MISCELLANEOUS PAPER GL-92-10

US Army Corps
of Engineers

EVALUATION OF GROUNDING AND MOORING POINTS FOR ARMY AIRCRAFT

by

Richard H. Grau, David L. Cooksey

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

April 1992
Final Report

GEOTECHNICAL LABORATORY

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1992

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Evaluation of Grounding and Mooring
Points for Army Aircraft

5. FUNDING NUMBERS

6. AUTHOR(S)
Richard H. Grau
David L. Cooksey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station
Geotechnical Laboratory, 3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper
GL-92-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road,
Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents results of tests conducted to evaluate the load capacity of aircraft mooring and grounding points. Both existing mooring points located at a military installation and newly designed systems were evaluated. Specifically, this report documents laboratory and field investigations on mooring systems to evaluate their ability to withstand anticipated forces applied by a moored Army aircraft during a 100-knot wind.

14. SUBJECT TERMS
Aircraft anchors — Mooring points
Grounding points — Shepherd hook

15. NUMBER OF PAGES
71

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

Preface

This study was sponsored by the US Army Corps of Engineers (USACE), Directorate of Military Programs during FY 90 and FY 91, and was conducted by the Geotechnical Laboratory (GL) of the US Army Engineer Waterways Experiment Station (WES). The USACE Technical Monitor was Mr. Paige E. Johnson.

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, WES and under the direct supervision of Mr. H. H. Ulery (retired), Drs. G. M. Hammitt II, Chief, Pavement Systems Division (PSD), and A. J. Bush III, Chief, Criteria Development and Applications Branch, PSD. The WES Principal Investigator, Mr. R. H. Grau, PSD, was assisted by Messrs. D. L. Cooksey and T. P. Williams, PSD. This report was prepared by Messrs. Grau and Cooksey.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms

EVALUATION OF GROUNDING AND MOORING POINTS FOR ARMY AIRCRAFT

Background

1. In May and June 1989, severe wind storms caused damage to more than 150 Army aircraft at Fort Hood, TX, and Fort Polk, LA. Between June 1989 and February 1990, several additional aircraft were damaged by wind storms. These incidents all involved aircraft tie-down and mooring practices. As a result of these incidents, a new manual, Technical Manual TM 1-1520-250-23-1 "General Tie-Down and Mooring on All Series Army Models AH-64, UH-60, CH-47, UH-1, AH-1, and OH-58 Helicopters" was issued by the US Army Aviation Systems Command. This technical manual required that the mooring points resist a 20,000-lb* load that can be applied in any direction around the point. In April 1990, Headquarters, US Army Corps of Engineers (HQUSACE) tasked the Transportation Systems Mandatory Center of Expertise (TSMCX) and US Army Engineer Waterways Experiment Station (WES) to develop jointly permanent Army aircraft mooring and ground point standard designs, details, guide specifications, testing procedures, and installation procedures. WES was specifically tasked to (a) analyze existing US manufactured aircraft mooring and grounding points' ability to withstand the new load requirements, (b) design new mooring and grounding points to withstand the new load requirements, and (c) construct and field test the designs to validate their structural capacity. In June 1990, an Engineer Technical Letter, ETL 1110-9-2 (FR) "Design of US Army Airfield Aircraft Mooring and Grounding Points for Rotary Wing Aircraft" was published. This letter provided interim guidance for the construction of mooring points that would resist a 20,000-lb force. In a meeting conducted on 13 September 1990 between personnel from the Army Aviation Systems Command and the Army Corps of Engineers, the load requirement was revised downward to 15,000 lb applied at 20.5 deg with the surface of the pavement.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Purpose

2. The purpose of this report is to present the results of tests conducted to analyze existing aircraft mooring and grounding points and newly designed points to determine their ability to withstand load requirements specified in Technical Manual TM 1-1520-250-23-1.

Scope

3. Field tests were conducted at Polk Army Airfield, LA, to determine is existing aircraft mooring points would withstand the 20,000-lb load requirement. The mooring points were conventional 6-ft-long, 5/8-in.-diam copper clad shepherd hooks that had been installed in a 6-in.-thick non-reinforced portland cement concrete parking pad. A discussion of the tests and results is presented in Appendix A.

4. Laboratory and field tests were conducted at WES on various mooring devices to determine if they would withstand sustained loadings of 15,000 lb. The resistance to ground of each anchor was also determined. Laboratory tensile tests were conducted on standard tie-down anchors and the equipment used to attach an aircraft to a mooring point. Field tests were conducted on five types of anchors that were installed in concrete slabs and on six types of anchors that were installed in a soil test section. A description of each anchoring system, the test conducted, and a discussion of the results are presented in Appendix B.

Results and Recommendations

Results

5. Results of tests conducted at Polk Army Airfield are as follows:

   a. The 6-ft-long, 5/8-in.-diam copper clad shepherd hooks that were installed in the portland cement concrete aircraft parking apron failed at maximum vertical forces of 9,460 and 13,000 lb.

   b. The maximum forces obtained when the direction of pull was 20 deg to the surface of the pavement ranged from 12,100 to 20,000 lb.

   c. The deflection of the anchors just prior to failure ranged from 1-1/4 to 1-15/16 in. when the force was applied perpendicular to the eye of anchor, whereas only 3/16-in. deflection was recorded when the force was applied parallel to the eye. The direction of force applied to each anchor and the corresponding deflection or movement are shown in Figure A3.

6. Results of the laboratory tests conducted on the anchors and the major items specified in Technical Manual TM 1-1520-250-23-1 for attaching aircraft to mooring points are:

   a. The anchors withstood tensile forces greater than the vertical component of the required 15,000-lb force.

   b. The chain and ratchet withstood forces greater than their working load limit of 10,000 lb.

   c. The coupling withstood forces greater than its working load limit of 3,500 lb.

7. Field tests conducted at WES on the various mooring systems indicated the following results:

   a. The resistance to ground of all of the anchoring systems was far less than the 10,000-ohm maximum requirement.

   b. The cast iron Neenah devices installed in the 6- and 8-in.-thick concrete slabs withstood forces greater than 15,000 lb, and none of the devices deflected visibly during the tests.

   c. The cast iron Neenah devices that were installed in the 1-1/-2ft-diam by 6-ft-deep reinforced concrete piers that were placed in the concrete slabs resisted forces greater than 15,000 lb, and no deflection occurred.

   d. All of the Neenah devices that were installed in the reinforced concrete piers that were placed in the soil test section withstood forces greater than 15,000 lb and did not deflect visibly during the tests. The 6-ft-deep piers moved between 1/16 and 1/8 in. during the tests, and the 4-ft-deep piers moved between 3/8 and 11/16 in.

e. All of the shepherd hooks that were driven into the soil prior to placement of the concrete slabs withstood forces greater than 15,000 lb, but their deflection ranged between 1 and 1-1/2 in.

f. The shepherd hooks that were retrofitted into the concrete slabs after the slabs had cured also withstood forces greater than 15,000 lb. The deflection of these anchors ranged between 7/8 and 1-1/2 in.

g. The shepherd hooks in the 4-ft-deep by 1.5- and 2-ft-diam concrete piers that were placed in the soil test section withstood forces greater than 15,000 lb, but deflections between 1-5/8 and 2 in. were measured. The concrete piers moved between 1/2 and 3/4 in.

h. The MR-2 anchor would not withstand the required force of 15,000 lb.

Recommendations

8. Based on the field and laboratory tests results, the following recommendations are warranted:

a. The 5/8-in.-diam standard shepherd hook anchors that are installed at most Army airfields can be expected to withstand the 15,000-lb load requirement, but they will deflect. It is suggested that if these type anchors are subjected to forces in the range of 15,000 lb, they should be inspected to determine if failure occurred.

b. The cast iron Neenah devices will withstand the load requirement and will not deflect.

c. The 3/4-in.-diam shepherd hook anchors will withstand the load requirement, but some deflection can be expected.

d. All of the concrete piers that were tested will withstand the required forces, but some movement of the piers can be expected.

e. The MR-2 anchors should not be used as mooring points for Army aircraft.

f. The anchoring systems met the requirement to provide a resistance to ground of 10,000 ohms or less.

Appendix A: Field Tests of Aircraft Mooring Points, 9 August 1990

CEWES-GP-N 9 Aug 90

MEMORANDUM FOR RECORD

SUBJECT: Field Tests of Aircraft Mooring Points

1. On 10 Jul 90, Messrs. Joe Ables and Tim Hawkins, ISD, and Tommy Williams and I visited Fort Polk, LA, to determine if existing aircraft mooring points would meet the interim requirements specified by the U.S. Army Aviation Systems Command. Mr. B. J. Skar, CEMRD-TSMCX, also visited Fort Polk during this period to observe and videotape the test procedures. Upon our arrival, we met with Mr. Ed Ducote, DEH, who had previously made arrangements for us to test anchors that had been installed on a parking apron at Polk Army Airfield (PAAF). Mr. Ducote and personnel from the airfield operations office accompanied us during the tests and provided us with the necessary equipment to conduct the tests.

2. The test site was a helicopter parking pad located on the south ramp of PAAF as shown on Figure A1. The ramp consisted of 6 in. of nonreinforced portland cement concrete placed on a 6-in. stabilized base. The subgrade was a silty sand. The mooring points were conventional 6-ft-long, 5/8 in.-diam copper clad shepherd hooks (see Figure A2). The concrete around the eye of each anchor was recessed so the top of the eye would be below the surface of the pavement and an aircraft mooring device could be attached to the eye. The distance from the top of the eye to the surface of the pavement averaged approximately 1/4 in.

3. Tests were conducted on eight anchors. The first two anchors were tested by applying forces to them in a vertical direction. The boom on a M-984 HEMMT was used to apply these forces. The direction of applied force to the other six anchors was 20 degrees to the surface of the pavement. During these tests, the HEMMT was used as a deadman and the force was applied with a ratchet-operated turnbuckle that had a 75-ton capacity. The direction of force was achieved by using an I-beam sled and wooden shims to elevate the connection between the turnbuckle and cable connected to the anchor to the proper height. A 20,000-lb dynamometer and strain indicator were used to determine the force. All test results are shown in Table A1, and anchor movement versus force determined during tests 3 to 8 are shown on Figure A3. Inserts on the figure depict original and deformed positions of the anchors and indicate where the anchor movement measurements were obtained.

4. Anchor movement of those anchors pulled at 20 degrees was obtained by scribing a mark on the pavement behind each anchor and measuring the distance between the mark and the head of the anchor as force was applied. Measurements were obtained at approximately 2,000-lb increments. No measurements were obtained on anchors that were pulled in a vertical direction.

5. The first two anchors tested were pulled in a vertical direction. The first anchor failed at 9,400 lb. This occurred when one side of the eye of the anchor appeared to have pulled loose from the copper sleeve that connects the anchor rod so it forms an eye. Loading of the second anchor was discontinued at 13,000 lb since this exceeded the latest requirement of 3,500 lb.

6. As shown in Table A1, the maximum forces obtained during the 20-degree pulls ranged from 12,100 to 20,000 lb. These forces were measured when the anchors failed, with the exception of test 4. Test 4 was discontinued when the force reached 20,000 lb because this met the latest requirements. Although the location of the anchors from a construction joint ranged from 1 to 5 ft, all failures were similar to the failure that occurred during the first test. No slab damage was observed during any of the eight tests. The significant difference in anchor movement shown for the last test was caused by the direction of applied force. In this test, the direction of force was rotated 90 degrees to the direction used during the five previous tests.

R. H. GRAU
Pavement Systems Division

Table A1

Mooring Point Test Results

Test	Direction of Force, deg*	Maximum Force, lb	Maximum Movement, in.
1	90	9,400	--
2	90	13,000	--
3	20	19,600	1-1/4
4	20	20,000	2-1/4
5	20	16,400	1-15/16
6	20	12,100	1-5/8
7	20	18,300	1-7/8
8	20	17,900	3/16

* Relative to surface of pavement.

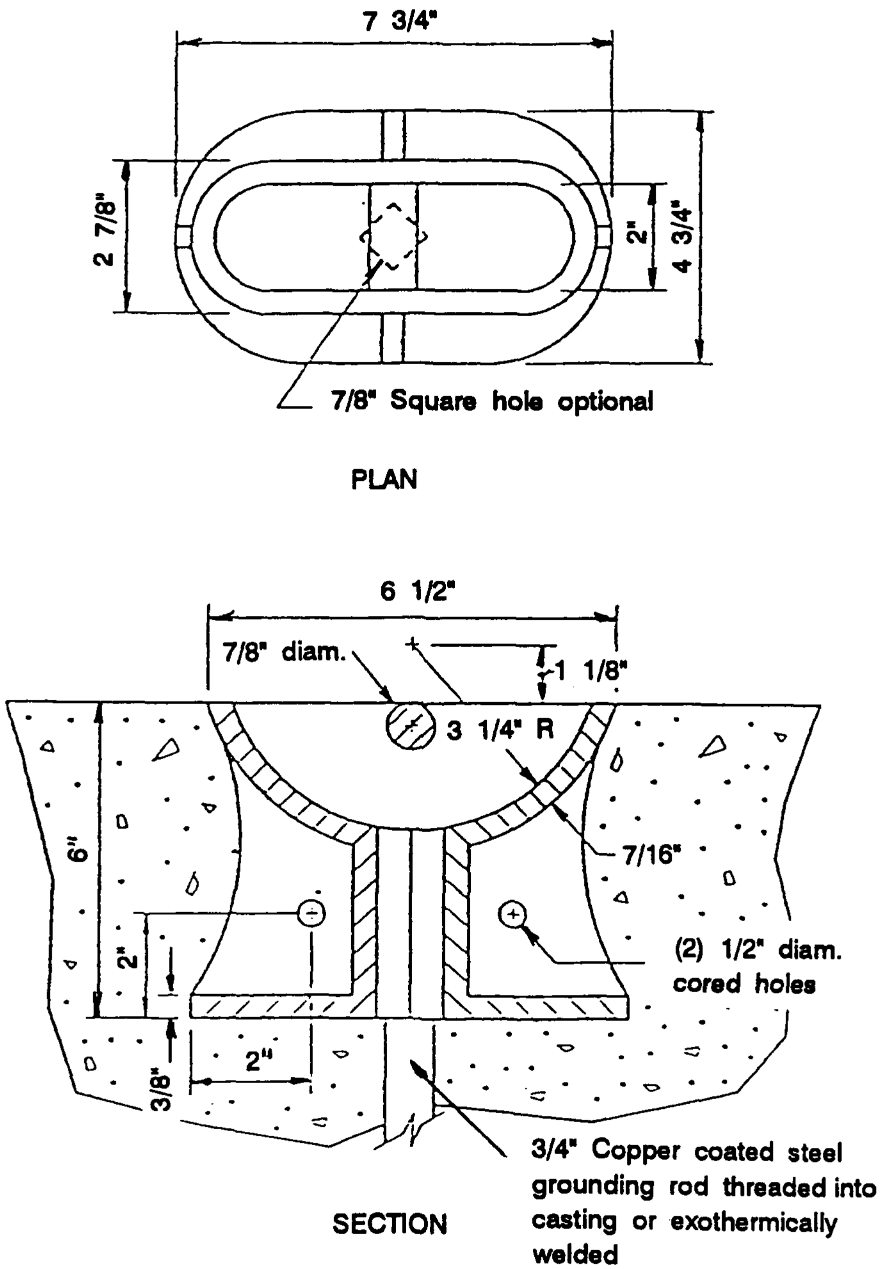


Figure A1. Mooring device

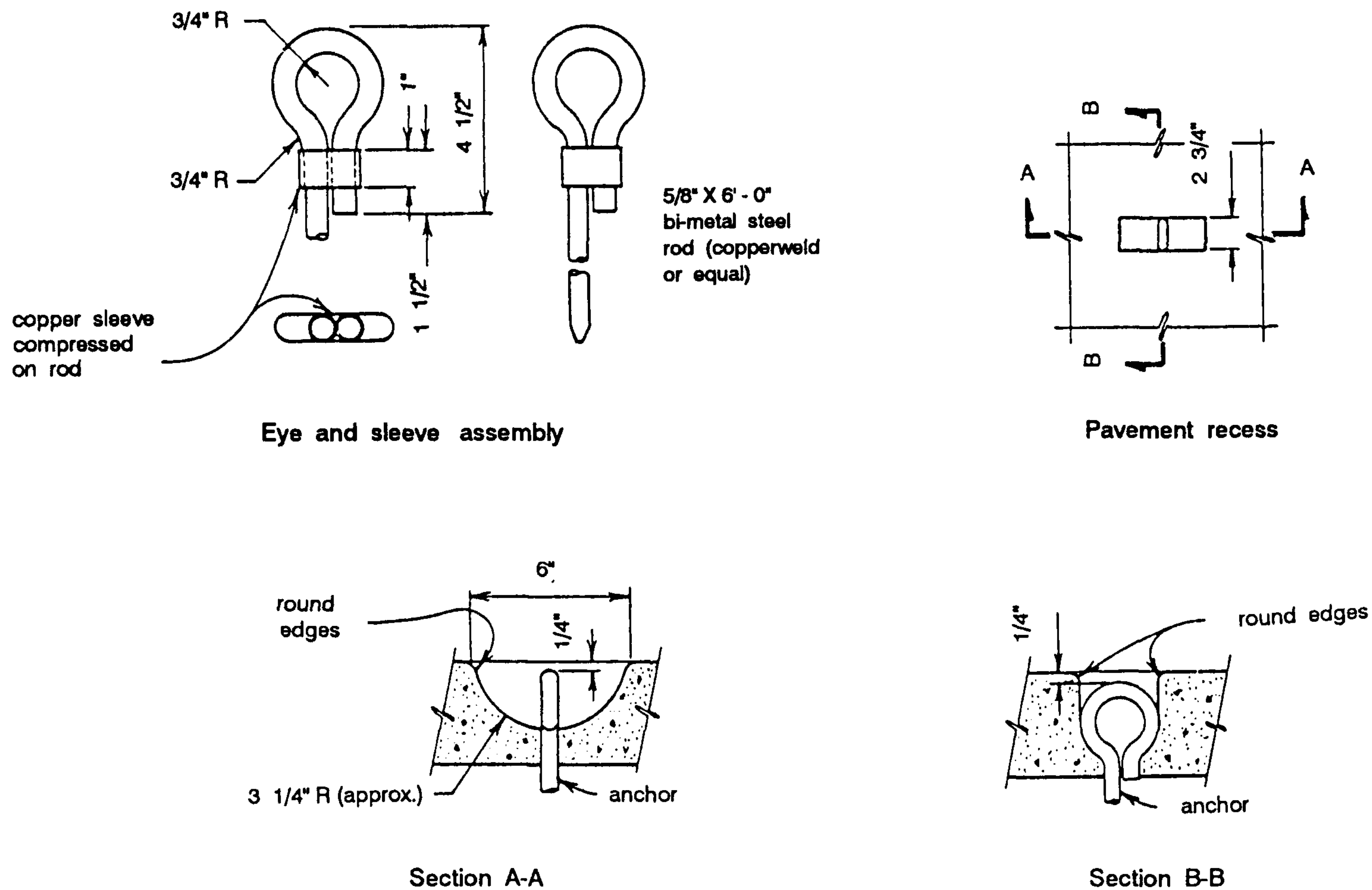


Figure A2. Shepherd hook mooring point

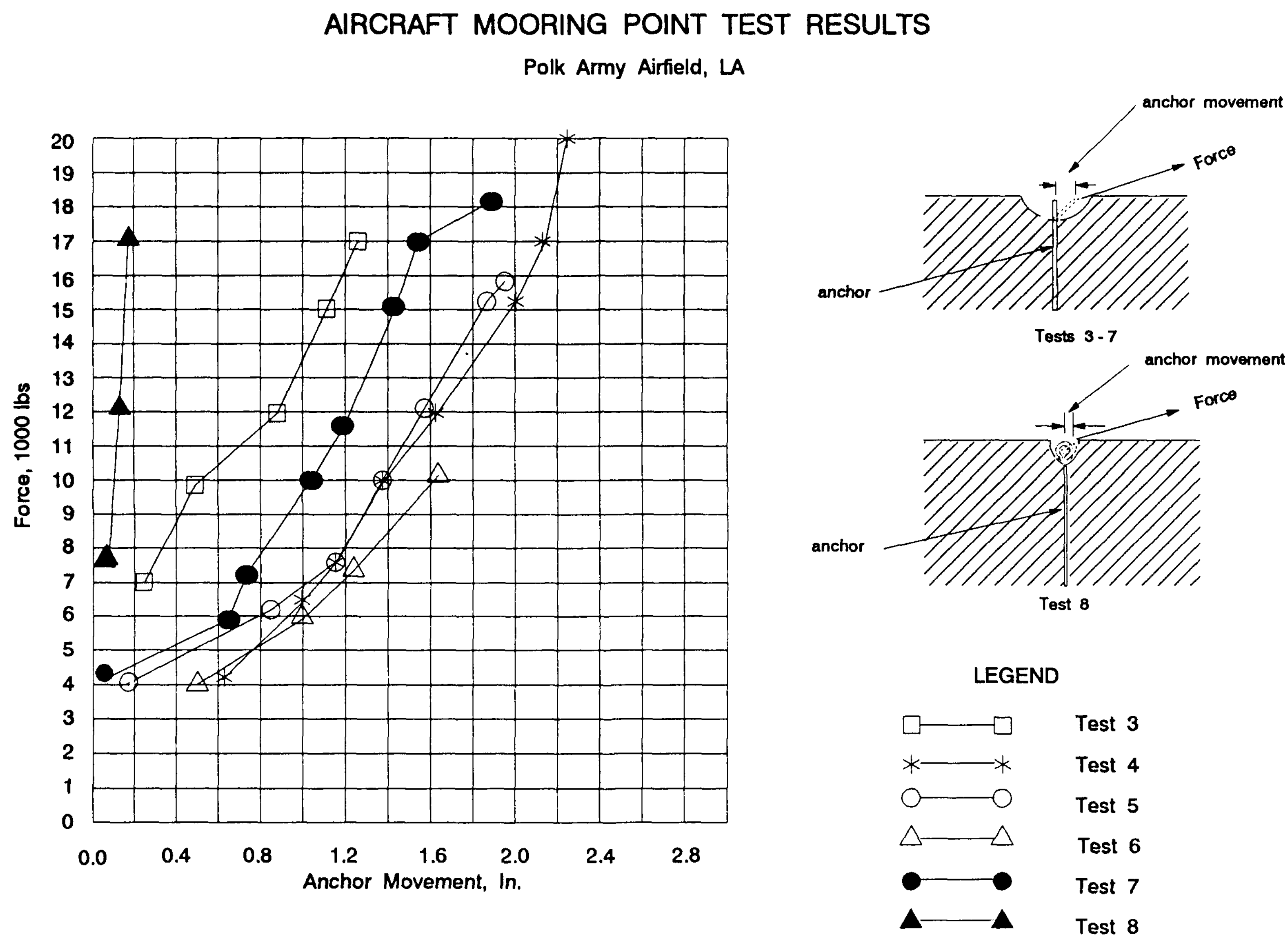


Figure A3. Anchor movement versus force, 20 deg inclination tests

Appendix B: Field Test of Aircraft Mooring Point, 29 April 1991

CEWES-GP-N 29 April 1991

MEMORANDUM FOR RECORD

SUBJECT: Field Test of Aircraft Mooring Points

1. Background. A memorandum from HQUSACE (CEMP-ET), subject: Mandatory Installation of Mooring and Grounding Points to Protect U.S. Army Aircraft, dated 18 March 1990, stated that in 1989 two separate wind storms caused damage to over 100 aircraft located on Army installations. These incidents involved the aircraft tie-down and mooring practices. As a result of these incidents, a new manual, TM 1-1520-250-23-1 "General Tie-down and Mooring Technical Manual," dated 25 September 1989 was issued. In April of 1990, HQUSACE tasked the TSMCX and WES to provide interim guidance, to oversee field testing, and to develop final guidance. Design of U.S. Army Airfield Aircraft Mooring and Grounding Points for Rotary Wing Aircraft, Engineer Technical Letter No. 1110-9-2 (FR), dated 12 June 1990, was published to provide interim U.S. Army Corps of Engineers design guidance regarding Army Airfield aircraft mooring and grounding points. A memorandum for Commander, U.S. Army Aviation Systems Command, ATTN: AMSAV-EIA/Bumbicka, 4300 Goodfellow Blvd, St. Louis, MO 61320-1798, dated 2 October 1990, subject: Army Aviation Systems Command/ Army Corps of Engineers Meeting, established a new load requirement of 15,000 lb at 20.5 degrees from the pavement surface. WES was tasked to analyze existing U.S. manufactured aircraft mooring and grounding points ability to withstand these new load requirements.

2. Purpose. This study was conducted to evaluate the adequacy of various mooring devices to sustain required loading of 15,000 lb at an angle of 20.5 degrees to the horizontal and to determine the resistivity of each anchor system tested.

3. Scope. Load tests were conducted on five types of anchors installed in concrete slabs and on six types of anchors in soils. Two types of anchors were installed before construction of concrete slabs and three were retrofitted in the constructed concrete slabs. Laboratory load tests were run on standard tie-down anchors (shepherd hooks), rods, chain and ratchets, and coupling devices. Resistance measurements were also taken.

ROUTING:

1. D. Grau
2. H. Ulery
3. P. Hadala
4. W. Marcuson
5.
6. D. Cooksey (file)

4. Description of anchors. The Neenah device as shown in Figure B1, is an airport mooring eye of oblong shape with dimensions of 7-3/4 in. long, 4-3/4 in. wide, and 6 in. thick. It has a 7/8 in. square hole through the bottom into which a 3/4-in. copper coated steel rod may be placed and welded to the device. It is made of cast ductile iron 80-55-06 or equal. The standard tie-down anchor (shepherd hook) is a 10-ft long copper coated steel rod with a shepherd hook on one end fastened with a metal strap (moulded) on the end (Figure B2). The Manta Ray Utility anchor resembles a star drill with a pair of wings, an attaching clevis for the anchor rod, and a drive rod receptacle on the opposite end of the star drill portion. The Manta Ray anchor is designed to be driven into the earth by a hydraulic or pneumatic jack hammer. A 90-lb jackhammer is recommended with an air compressor having at least a 100-cfm capacity. The complete installation consists of the Manta Ray anchor, a screw anchor rod, a guy rod extension, if needed, and the appropriate thimble eye nut (Photos B1 and B2).

5. Laboratory tests. Tensile tests were conducted on the eyes and shafts of the standard tie-down anchors and the major equipment specified in TM 1-1520-250-23-1 to be used for attaching aircraft to mooring points. These tests were conducted to determine if the various items would withstand the maximum predicted loads. The tests were conducted in accordance with the methods described in ASTM A 370, "Mechanical Testing of Steel Products" for determining tensile properties of materials. A Baldwin-Southwark testing machine was used to conduct the tests.

6. Laboratory test results. Photo B3 shows an example of each of the items after the tests were completed. Results of the tests are listed in Table B1. As shown in the table, all of the test items withstood a force greater than 5,250 lb which is the vertical component of the 15,000 lb directed at 20.5 degrees to the horizontal. The coupling link, which is listed at a working load limit of 3,500 lb, withstood a tensile force of 5,600 lb.

7. Test site. A site was selected in the north end of Hangar No. 4 at WES. Figure B3 provides a layout of the concrete slab test site, and Figure B4 is a layout of soil test site. The soil beneath the concrete slab test site consisted of lean clay (CL) down to a measured depth of 6 ft. The soil test site consisted of 4 in. of crushed limestone over 5-2/3 ft of lean clay for anchors 2A-A, 2A-B, 3A-A, and 3B-B; 1-1/2 ft of buckshot over 4-1/2 ft of lean clay for anchors 2C-A, 2C-B, 3C-A, and 3C-B; and 2 ft of buckshot over 4 ft of lean clay for tests 4A-A, 4A-B, 4B-A, and 4B-B. The soil below the test section was sandy silt. Strength tests were run on the in situ soil using the dynamic cone penetrometer (DCP). The results are shown in Table B2. Also shown in Table B2 are CBR values deduced from correlations with the DCP.

8. Concrete test section construction. The area where the concrete slab test section (Figure B3) was to be located was leveled with a grader, and a

thin layer of sand was placed. The concrete was placed in two 30- by 15-ft concrete slabs, 8 in. and 6 in. thick. Anchors 1A (8-in. slab), 1B (8-in. slab), 1C (6-in. slab), and 1D (6-in. slab) (Neenah devices) were installed as shown in Figures B1 and B5 (Photo B4). These devices consisted of 10-ft rods (copper coated steel grounding rod) welded to a Neenah mooring device. The device was driven into the ground to a depth so that its top was at the same elevation as the top of the concrete slab. The anchors were installed before the concrete was placed. Anchors 2A, 2B, 2C, and 2D were standard tie-down anchors installed as shown in Figure B2 (Photo B5). These anchors were installed before the concrete was placed by driving them into the soil with a post driver. Metal forms (Photo B6) with a diameter of 20 in. and a depth equal to the depth of the concrete to be placed were installed to provide holes in the concrete for installing Neenah anchors 3A, 3B, 3C, and 3D. The metal forms were filled with limestone to prevent concrete from entering the hole during placement (Photo B7). After the concrete was placed and cured, the metal forms were removed, 1-1/2-ft-diam by 6-ft deep holes were augered, and the anchors were installed as shown in Figure B6. Photo B8 shows a typical cage of reinforcing steel used. Photo B9 shows anchor 3B installed in the 1-1/2-ft-diam and 6-ft-deep augered hole ready for concrete. Plastic forms with a diameter of 8 in. and a depth according to the depth of the concrete were placed to provide holes for standard tie-down anchors 4A, 4B, 4C, and 4D. After the concrete was placed and cured, the plastic forms were removed and the anchors installed as shown in Figure B7. Photo B10 shows anchor 4A ready for the concrete to be placed. Plastic forms with a diameter of 8 in. and a depth equal to the depth of the concrete to be placed were installed to provide holes for the Manta-Ray Anchors 4E, 4F, 4G, and 4H. After the concrete was placed and cured, the plastic forms were removed. The Manta-Ray Anchors (MR-2) in Photo B1 were placed in the holes and driven into the ground using a hydraulic jack hammer as shown in Photo B2. The complete installation consisted of the Manta-Ray Anchor, a screw anchor rod, and a thimble nut to attach an anchoring cable. After the anchor was driven to a depth of 8 ft, a load-locking device was attached to the screw anchor rod. The anchor rod was pulled vertically using the load locker, thereby rotating the anchor to a horizontal position in the undisturbed soil. A gage on the Load Locker that measured applied force indicated when the anchor rotated to a horizontal position and when holding capacity had been attained. Photo B11 shows the completed concrete test section after the concrete had been placed.

9. <u>Soil test section construction</u>. The soil test site was bladed and the site was laid out (Figure B4). Photo B12 shows the drilling rig used to auger holes for piers. Anchors 2A-A and 2A-B were constructed as shown in Figure B8. Photo B13 shows anchor 2A-A ready for the placement of concrete. Anchors 2C-A and 2C-B were constructed as shown in Figure B10. Photo B14 shows Anchor 3A-A ready for placement of concrete. Anchors 3C-A and 3C-B were constructed according to Figure B11. Anchors 4A-A and 4A-B were constructed as shown in Figure B12. Anchors 4B-A and 4B-B were constructed as shown in Figure B13. Photo B15 shows anchor 4B-A ready for placement of concrete.

Photo B16 shows all anchors prepared to the point of being ready for placement of concrete. Photo B17 shows the concrete piers completed and ready for load pull test.

10. Resistance tests. Measurements were obtained to determine the relative electrical resistance between similar anchors. A two-terminal method as described in paragraph 5.3.2 of MIL-HDBK-274(AS),* with the exception that adjacent similar anchors were used as an earth ground instead of a metallic water pipe system, was used to make these measurements.

11. Resistance test results. Results of the resistance test are shown in Table B3. As shown, all of the measurements were far below the requirement of 10,000 ohms. Resistance of these anchor systems will change dramatically in different soils since their resistivity is greatly influenced by soil type, moisture content, pH, height of water table, etc.

12. Load test. Load was applied to the anchors using a crane with a cable attachment as shown in Photo B18. Prior to applying a load to an anchor, the crane was positioned so that the force would be applied at an angle of 20.5 degrees to the horizontal plane. Each anchor device was subjected to a 2,000-lb (approximate) incremental increase in load up to 20,000 lb (approximate) or until the anchoring device failed. A dynamometer was used to measure the applied force in pounds. Deflection of the anchors in concrete and anchors and the piers in the soil were measured and recorded. Results of load tests are shown in Table B4, and a summary of results is shown in Tables B5 and B6.

13. Performance of anchors was as follows:

a. Anchors 1A and 1B were Neenah devices in an 8-in. concrete slab and had no visible deflection for all loads.

b. Anchors 1C and 1D were Neenah devices in a 6-in. concrete slab and had no visible deflection for all loads. Photo B19 shows one of the devices after the load test was completed.

c. Anchors 2A and 2B were standard tie-down anchors (shepherd hooks) in an 8-in. concrete slab and deflected 1-1/2 and 1-5/16 in. at 16,010 and 15,860 lb, respectively. Photo B20 shows one of the devices after the load tests were complete. An example of eye deflection of a shepherd hook anchor is shown in Photo 21.

---

* Military Handbook. 1983 (Nov). "Electrical Grounding for Aircraft Safety," MIL-HDBK-274(AS), Naval Air Systems Command, Washington, DC.

d. Anchors 2C and 2D were standard tie-down anchors (shepherd hooks) in a 6-in. concrete slab and deflected 1 and 1-1/8 in. at 17,220 and 16,470 lb, respectively.

e. Anchors 3A and 3B were Neenah devices in an 8-in. concrete slab and had no visible deflection for all loads.

f. Anchors 3C and 3D were Neenah devices in a 6-in. concrete slab and had no visible deflection for all loads.

g. Anchors 4A and 4B were standard tie-down anchors (shepherd hooks) in an 8-in. concrete slab and both deflected 1-1/8 in. at 17,450 and 15,000 lb, respectively. Photo B21 shows one of the devices after the load test were completed.

h. Anchors 4C and 4D were standard tie-down anchors in a 6-in. concrete slab and deflected 1-1/2 and 7/8-in. at 16,720 and 16,470 lb, respectively.

i. Anchor 4F (Manta Ray MR-2) failed at 4,560 lb. This type of anchoring device was considered unsatisfactory; therefore, anchors were not tested.

j. Anchors 2A-A and 2A-B (Neenah devices in a 2-ft-diam 6-ft-deep concrete pier) both had no visible deflection of the anchoring eye rod and deflections of 1/8 and 1/16 in. of the concrete pier at 18,340 and 15,200 lb, respectively. Photo B22 shows one of the devices after the load tests were completed.

k. Anchors 3A-A and 3A-B (Neenah devices in a 1.5-ft-diam 6-ft-deep concrete pier) both had no visible deflection of the anchoring eye rod and deflections of 1/8 and 1/16 in. of the concrete pier at 15,730 and 15,990 lb, respectively.

l. Anchors 2C-A and 2C-B (Neenah devices in 2-ft-diam 4-ft-deep concrete pier) both had no visible deflection of the anchoring eye rod and deflections of 11/16 and 3/8 in. of concrete pier at 21,860 and 18,240 lb, respectively.

m. Anchors 3C-A and 3C-B (Neenah devices in a 1.5-ft-diam 4-ft-deep pier) both had no visible deflection of the anchoring eye rod and deflections of 1/2 and 3/8 in. of the concrete pier at 16,300 and 15,260 lb, respectively.

n. Anchors 4A-A and 4A-B (standard tie-down anchor in a 2-ft-diam 4-ft-deep concrete pier) had 1-7/8 and 2-in. deflection of the anchoring eye rod and deflections of 1/2 and 3/4 in. of the concrete pier at 18,300 and 16,780 lb, respectively. Photo B23 shows one of the devices after the load test was completed.

o. Anchors 4B-A and 4B-B (standard tie-down in a 1.5-ft-diam 4-ft-deep pier) had 1-5/8 and 1-3/4-in. deflection of the anchoring eye rod and deflections of 5/16 and 3/4 in. deflections of the concrete pier for loads of 15,250 and 15,250 lb, respectively. After increasing the load on anchor 4B-B to 17,300 lb, the pier pulled loose from the soil. Photo B24 shows anchor 4B-B after the load test was complete.

14. Conclusions and recommendations. The following conclusions and recommendations resulted from this study:

a. Laboratory test indicated that all rods and eyes of the anchors withstood forces greater than 5,250 lb which is the vertical component of 15,000 lb at 20.5 degrees. The coupling link also withstood a force greater than its listed working load.

b. Resistivity test indicated all anchors provided a resistance of less than 10,000 ohms.

c. Field tests indicated the following:

(1) Neenah devices can resist the required loads with no deformation.

(2) Manta Rays are unsatisfactory.

(3) Three-fourth in. standard tie-down anchors are adequate for loads in the 10,000- to 15,000-lb range but some deformation can be expected.

(4) Six feet deep, 1.5-ft, or 2.0-ft diam concrete piers withstood required loads.

d. Based on the results of this study, the Neenah device or the 3/4-in.-diam by 10-ft long standard tie-down anchors (shepherd hook) are recommended for Army aircraft mooring points.

DAVID L. COOKSEY
Civil Engineer
Pavement Systems Division

Table B1

Laboratory Test Results* on the Tie-Down Devices

Description	Span Length in.	Rate of load in./min	Time min	Elongation in.	Total Load, lb
5/8 in. rod (1D1058)	6	0.375	1	0	15,000
5/8 in. rod (1D1058)	6	0.200	1 1/4	0	15,000
5/8 in. rod (1D1058)	6	0.200	4 1/2	9/16	20,000
3/4 in. rod (1D1034)	6	0.200	1 1/4	0	15,000
3/4 in. rod (1D1034)	6	0.200	1	0	15,000
1 in. rod (craft 101)	6	0.200	2	0	15,000
1 in. rod (craft 101)	6	0.200	1 1/2	0	15,000
5/8 in. Standard Tie-down anchors (Shepherd Hooks)	6	0.200	7 1/4	0	6,200**
5/8 in. Standard Tie-down anchors (Shepherd Hooks)	6	0.200	8	0	7,750**
3/4 in. Standard Tie-down anchors (Shepherd Hooks)	6	0.200	9 1/4	0	12,000†
chain and ratchet	--	0.200	8	--	11,500††
coupling (577-0415)	--	0.200	3 1/2	--	3,500
coupling (577-0415)	--	0.200	+3 3/4	--	5,600‡

* Tested in accordance with ASTM A 370.
** Hook opened and load reduced.
† Rods slipped in the clamp and load fell off.
†† Passed required 10,000 lb.
‡ No failure.

Table B2

DCP DATA SHEET

Project Anchor Evaluation Date

Location Anchors 2A-A and 3A-A area Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 1							
0	0						
10	55	55	5.5	1	5.5	40	0
5	95	40	8	1	8	30	2.2
5	140	45	9	1	9	25	3.7
5	200	60	12	1	12	19	5.5
5	280	80	16	1	16	13	7.9
5	345	65	13	1	13	16	11.0
5	405	60	12	1	12	18	13.6
5	465	60	12	1	12	18	15.9
5	535	70	14	1	14	15	18.3
5	610	75	15	1	15	14	21.1
5	705	95	19	1	19	11	24.0
5	760	55	11	1	11	20	27.8
5	795	35	7	1	7	35	29.9
5	835	40	8	1	8	30	31.3

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
 (Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 1 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchors 2C-A and 3C-A area Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 2							
0	0						
5	40	40	8	1	8	30	0
5	65	25	5	1	5	50	1.6
5	92	30	6	1	6	40	2.6
5	125	30	6	1	6	40	3.7
5	160	35	7	1	7	35	4.9
5	195	35	7	1	7	35	6.3
5	240	45	9	1	9	25	7.7
5	330	90	18	1	18	11	9.4
5	480	150	30	1	30	6	13.0
5	540	60	12	1	12	18	18.9
5	575	35	7	1	7	35	21.3
5	605	30	6	1	6	40	22.6
5	645	40	8	1	8	30	23.8
5	705	60	12	1	12	18	25.4
5	740	35	7	1	7	35	27.8
5	760	20	4	1	4	60	29.1
5	785	25	5	1	5	50	29.9
5	815	30	6	1	6	40	30.9

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows (Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 2 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchors 4A-A and 4A-B area Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 3							
0	0						
5	70	70	14	1	14	15	0
5	180	110	22	1	22	9	2.8
5	275	95	19	1	19	11	7.1
5	310	35	7	1	7	35	10.8
5	355	45	9	1	9	25	12.2
5	400	45	9	1	9	25	14.0
5	450	50	10	1	10	20	15.7
5	500	50	10	1	10	20	17.7
5	560	60	12	1	12	18	19.7
5	640	80	16	1	16	13	22.0
5	720	80	16	1	16	13	25.2
5	770	50	10	1	10	20	28.3
5	815	45	9	1	9	25	30.3
5	860	45	9	1	9	25	32.1

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 3 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchor 4A Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 1							
0	20						
3	80	60	20	1	20	10	0.8
5	115	35	7	1	7	35	3.1
10	195	80	8	1	8	30	4.5
10	270	75	7.5	1	7.5	33	7.7
10	350	80	8	1	8	30	10.6
8	470	120	15	1	15	14	13.8
3	525	55	18.3	1	18.3	11	18.5
3	635	110	36.7	1	36.7	5	20.7
2	730	95	47.5	1	47.5	3.8	25.0
1	790	60	60	1	60	3	28.7

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 4 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchor 4B Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 2							
0	0						
6	95	95	15.8	1	15.8	13.0	0
10	190	95	9.5	1	9.5	22.5	
7	260	70	10	1	10	20	
10	345	85	8.5	1	8.5	28.5	
10	410	65	6.5	1	6.5	37.5	
10	480	70	7	1	7	35	
10	550	70	7	1	7	35	
10	630	80	8	1	8	30	
10	710	80	8	1	8	30	
10	785	75	7.5	1	7.5	32.5	

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 5 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchor 4D Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 6							
0	0						
5	60	60	12	1	12	18	0
10	125	65	6.5	1	6.5	35	2.4
10	190	65	6.5	1	6.5	35	4.9
10	245	55	5.5	1	5.5	40	7.5
10	295	50	5	1	5	40	9.6
10	335	40	4	1	4	60	11.6
10	370	35	3.5	1	3.5	60	13.2
10	400	30	3	1	3	80	14.6
10	430	30	3	1	3	80	15.7
10	465	35	3.5	1	3.5	60	16.9
10	495	30	3	1	3	80	18.3
10	525	30	3	1	3	80	19.5
10	555	30	3	1	3	80	20.7
10	575	20	2	1	2	100	21.9
10	605	30	3	1	3	80	22.6
10	635	30	3	1	3	80	23.8
10	665	30	3	1	3	80	25.0
10	695	30	3	1	3	80	26.2
10	725	30	3	1	3	80	27.4
10	760	35	3.5	1	3.5	60	28.5
10	800	40	4	1	4	60	29.9
10	830	30	3	1	3	60	31.5

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 6 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchor 4E Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 3							
0	0						
10	140	140	14	1	14	15	0
9	280	140	15.6	1	15.6	13.4	5.5
10	490	210	21	1	21	10	11.0
3	620	130	43.3	1	43.3	4.3	19.3
3	730	110	36.7	1	36.7	5	24.4
3	840	110	36.7	1	36.7	5	28.7

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 7 of 9)

Table B2 (Continued)

Project Anchor Evaluation Date

Location Anchor 4G Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 4							
0	0						
5	100	100	50	1	50	3.7	0
7	180	80	11.4	1	11.4	20	3.9
10	280	100	10	1	10	20	7.1
3	340	60	20	1	20	10	11.0
3	410	70	23.3	1	23.3	9	13.4
3	460	50	16.7	1	16.7	12	16.1
4	560	100	25	1	25	8	18.1
3	670	110	36.7	1	36.7	5	22.0
2	750	80	40	1	40	4.7	26.4
2	840	90	45	1	45	4.1	29.5

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) (2) divided by 2.54 rounded off to .1 in.

(Sheet 8 of 9)

Table B2 (Concluded)

Project Anchor Evaluation Date

Location Anchor 4H Soil Type(s)

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
Hole 5							
0	0						
5	90	90	18	1	18	11	0
5	130	40	8	1	8	30	3.5
5	180	50	10	1	10	20	5.1
5	210	30	6	1	6	40	7.1
10	280	70	7	1	7	35	8.3
10	360	80	8	1	8	30	11.0
10	450	90	9	1	9	25	14.2
10	540	90	9	1	9	25	17.7
10	630	90	9	1	9	25	21.3
10	720	90	9	1	9	25	24.8
10	800	80	8	1	8	30	28.3

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From Table 1
(8) *(2) divided by 2.54 rounded off to .1 in.*

(Sheet 9 of 9)

Table B3

Direct Current Resistance Measured Between the Rods

Rods	Resistance, ohms
1A-1B	35
2A-2B	55
3A-3B	15
4A-4B	45
4E-4F	45
1C-1D	35
2C-2D	45
4C-4D	43
4G-4H	67
2AA-2AB	15
2CA-2CB	21
3AA-3AB	11
3CA-3CB	26
4AA-4AB	45
4BA-4BB	45

Table B4

Results of Anchor Evaluation Tests

Forces, lb	Deflection, in.	Forces, lb	Deflection, in.
8-in.-thick Slab			
Anchor 1A (Neenah)		Anchor 1B (Neenah)	
3,530	0	3,800	0
4,360	0	5,780	0
7,140	0	9,030	0
11,410	0	11,800	0
16,020	0	15,260	0
20,900	0	18,320	0
		23,300	0
6-in.-thick Slab			
Anchor 1C (Neenah)		Anchor 1D (Neenah)	
3,780	0	3,220	0
6,890	0	8,750	0
10,130	0	12,580	0
14,520	0	16,360	0
17,550	0	20,270	0

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.	Forces, lb	Deflection, in.
8-in.-thick Slab			
Anchor 2A (Standard Tie-down)		Anchor 2B (Standard Tie-down)	
2,020	0	2,530	0
6,300	0	6,620	1/16
8,630	1/16	9,650	3/8
10,540	3/4	11,750	15/16
12,310	1	15,860	1 5/16
13,750	1 1/4	18,240	1 3/8
16,010	1 1/2	20,270	1 7/16
19,300	2		
21,130	2 1/8		
6-in.-thick Slab			
Anchor 2C (Standard Tie-down)		Anchor 2D (Standard Tie-down)	
3,200	0	3,500	0
5,420	0	7,090	0
7,860	1/8	11,010	1/8
11,030	3/16	13,370	3/4
13,580	5/8	16,470	1 1/8
17,220	1	19,280	1 1/4
22,260	1 1/4	21,810	1 1/4
23,290	1 1/4		

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.	Forces, lb	Deflection, in.
8-in.-thick Slab			
Anchor 3A (Neenah)		Anchor 3B (Neenah)	
4,220	0	2,530	0
6,940	0	4,760	0
9,180	0	7,200	0
14,190	0	9,630	0
17,480	0	13,730	0
22,290	0	15,780	0
		18,240	0
		21,090	0
6-in.-thick Slab			
Anchor 3C (Neenah)		Anchor 3D (Neenah)	
3,550	0	5,370	0
7,090	0	8,610	0
11,080	0	11,650	0
13,680	0	16,720	0
16,460	0	19,270	0
18,350	0	21,790	0
22,800	0		

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.	Forces, lb	Deflection, in.
8-in.-thick Slab			
Anchor 4A (Standard Tie-down)		Anchor 4B (Standard Tie-down)	
2,950	0	2,000	0
6,000	0	4,000	0
8,170	11/16	6,000	0
10,160	11/16	8,000	0
14,030	7/8	10,000	0
17,450	1 1/8	12,000	0
22,130	1 3/8	14,000	1/4
		15,000	1 1/8
		15,700	1 1/4
		23,100	1 1/2
6-in.-thick Slab			
Anchor 4C (Standard Tie-down)		Anchor 4D (Standard Tie-down)	
3,800	0	2,230	0
6,090	0	4,810	0
8,110	1/8	5,790	0
11,150	3/8	9,460	0
12,700	5/8	13,170	1/4
14,470	1 1/8	14,490	5/8
16,720	1 1/2	16,470	7/8
18,440	1 3/4	19,640	1 1/2
21,780	1 7/8	22,800	1 3/4

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.	Forces, lb	Deflection, in.
	8-in.-thick Slab		
Anchor 4F (Manta MR-2)		Anchor (Manta MR-2)	
3,290	1/2	--	--
4,360	3/4	--	--
4,560	Failed	--	--

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.		Forces, lb	Deflection, in.	
Anchor 2A-A (2 ft diam x 6 ft deep, Neenah)			Anchor 2A-B (2 ft diam x 6 ft deep, Neenah)		
	Anchor	Pier		Anchor	Pier
2,000	0	0	2,270	0	0
4,030	0	0	3,600	0	0
6,840	0	1/6	7,690	0	1/16
10,410	0	1/8	9,040	0	1/16
13,220	0	1/8	11,700	0	1/16
18,340	0	1/8	15,200	0	1/16
21,320	0	3/16	18,740	0	1/8
			25,030	0	1/8
Anchor 3A-A (1.5 ft diam x 6 ft deep, Neenah)			Anchor 3A-B (1.5 ft diam x 6 ft deep, Neenah)		
	Anchor	Pier		Anchor	Pier
2,390	0	0	2,830	0	0
7,630	0	1/16	6,210	0	0
11,540	0	1/16	7,980	0	0
15,730	0	1/8	12,740	0	1/16
20,950	0	1/8	15,990	0	1/16
			20,480	0	1/8

(Continued)

Table B4 (Continued)

Forces, lb	Deflection, in.		Forces, lb	Deflection, in.	
Anchor 2C-A (2 ft diam x 4 ft deep, Neenah)			Anchor 2C-B (2 ft diam x 4 ft deep, Neenah)		
	Anchor	Pier		Anchor	Pier
2,210	0	0	5,670	0	1/16
3,380	0	1/16	9,900	0	3/16
5,670	0	1/8	14,740	0	1/4
7,770	0	1/8	18,240	0	3/8
11,020	0	1/4	21,580	0	1/2
14,270	0	3/8			
21,860	0	11/16			
Anchor 3C-A (1.5 ft diam x 4 ft deep, Neenah)			Anchor 3C-B (1.5 ft diam x 4 ft deep, Neenah)		
	Anchor	Pier		Anchor	Pier
3,200	0	1/16	3,830	0	1/16
6,590	0	1/8	6,510	0	1/8
8,110	0	3/16	8,640	0	3/16
10,740	0	1/4	11,620	0	1/4
14,480	0	3/8	15,260	0	3/8
16,300	0	1/2	16,080	0	5/16
21,790	0	7/8	20,330	0	1/2

(Continued)

Table B4 (Concluded)

Anchor 4A-A
(2 ft diam x 4 ft deep,
Standard Tie-down)

Forces, lb	Deflection, in. Anchor	Deflection, in. Pier
3,270	0	0
6,030	1/16	1/16
8,340	1/8	1/16
10,820	1 1/4	3/16
13,780	1 1/2	1/4
18,300	1 7/8	1/2
22,390	2 1/2	

Anchor 4A-B
(2 ft diam x 4 ft deep
Standard Tie-down)

Forces, lb	Deflection, in. Anchor	Deflection, in. Pier
2,120	0	0
4,780	0	0
6,090	1/8	1/8
9,120	1/4	1/4
11,150	3/4	3/8
13,890	1 1/2	1/2
16,780	2	3/4
19,710	2 1/2	1 1/4

Anchor 4B-A
(1.5 ft diam x 4 ft deep,
Standard Tie-down)

Forces, lb	Deflection, in. Anchor	Deflection, in. Pier
5,800	1/16	1/16
8,620	1/2	1/8
10,820	3/4	3/16
12,460	1	3/16
15,250	1 5/8	5/16
17,930	1 3/4	7/16
20,160	2	9/16

Anchor 4B-B
(1.5 ft diam x 4 ft deep
Standard Tie-down)

Forces, lb	Deflection, in. Anchor	Deflection, in. Pier
2,780	0	1/16
7,800	1/8	1/16
11,650	1	1/4
15,250	1 3/4	3/4
16,670	2 1/4	1 1/4
17,300	3 1/4	4 1/2

Note: Pier pulled loose

(Page 8 of 8)

Table 5

Summary of Anchor Deflections in Concrete Slab

Anchor Type	Test Load, lb	Deflections of Test Load, in.
1A	20,900	0
1B	23,300	0
1C	17,500	0
1D	20,270	0
2A	16,010	1 1/2
2B	15,860	1 5/16
2C	17,220	1
2D	16,470	1 1/8
3A	22,290	0
3B	21,090	0
3C	22,800	0
3D	21,790	0
4A	17,450	1 1/8
4B	15,000	1 1/8
4C	16,720	1 1/2
4D	16,470	7/8
4E	Not tested due to failure of Anchor 4F	
4F	4,560	Failure
4G	Not tested due to failure of Anchor 4F	
4H	Not tested due to failure of Anchor 4F	

Table 6

Summary of Test Results Concrete Piers in Soil Test Site

Anchor Type	Test Load, lb	Deflection, in.	
		Anchor	Pier
2A-A	18,340	0	1/8
2A-B	15,200	0	1/16
3A-A	15,730	0	1/8
3A-B	15,990	0	1/16
2C-A	21,860	0	11/16
2C-B	18,240	0	3/8
3C-A	16,300	0	1/2
3C-B	15,260	0	3/8
4A-A	18,300	1 7/8	1/2
4A-B	16,780	2	3/4
4B-A	15,250	1 5/8	5/16
4B-B	15,250	1 3/4	3/4

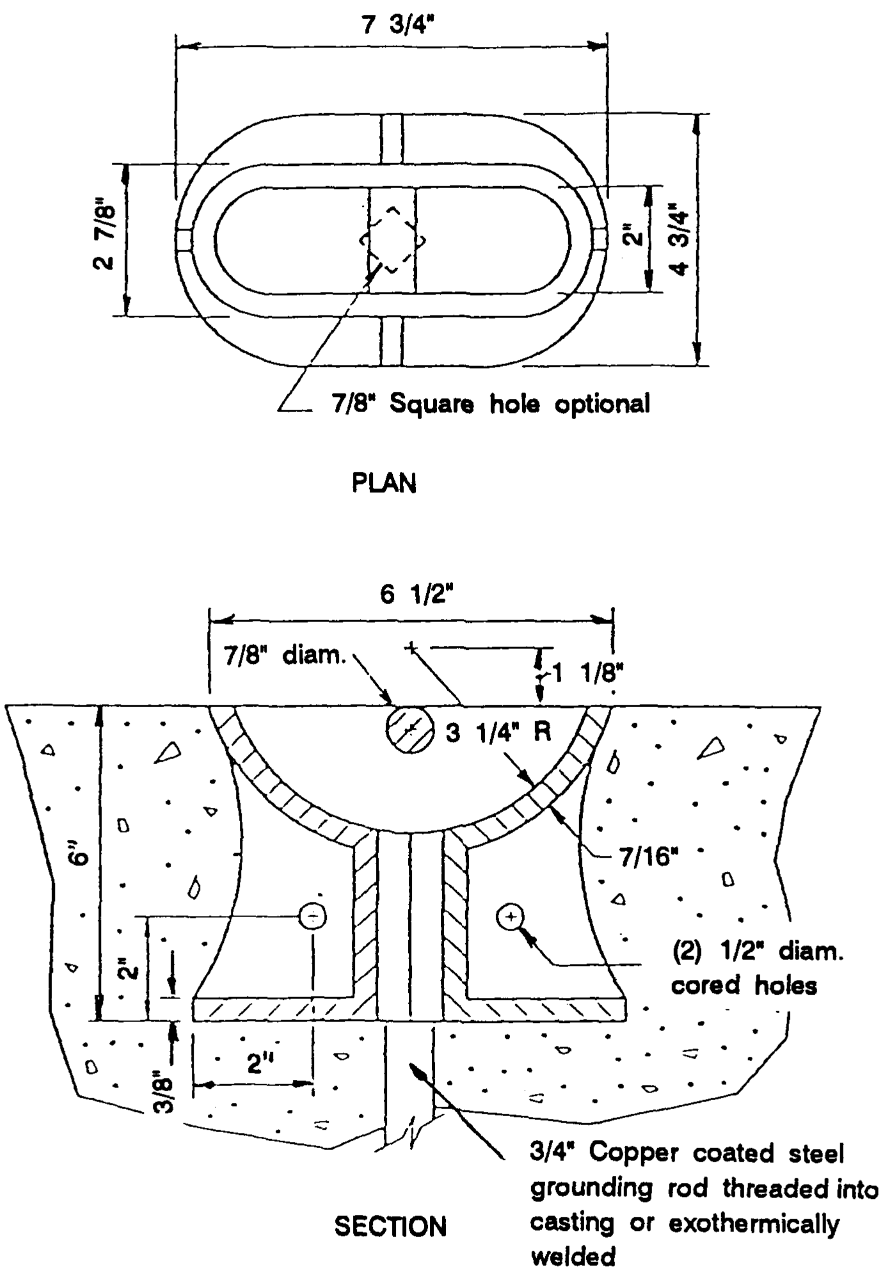


Figure B1. Mooring device

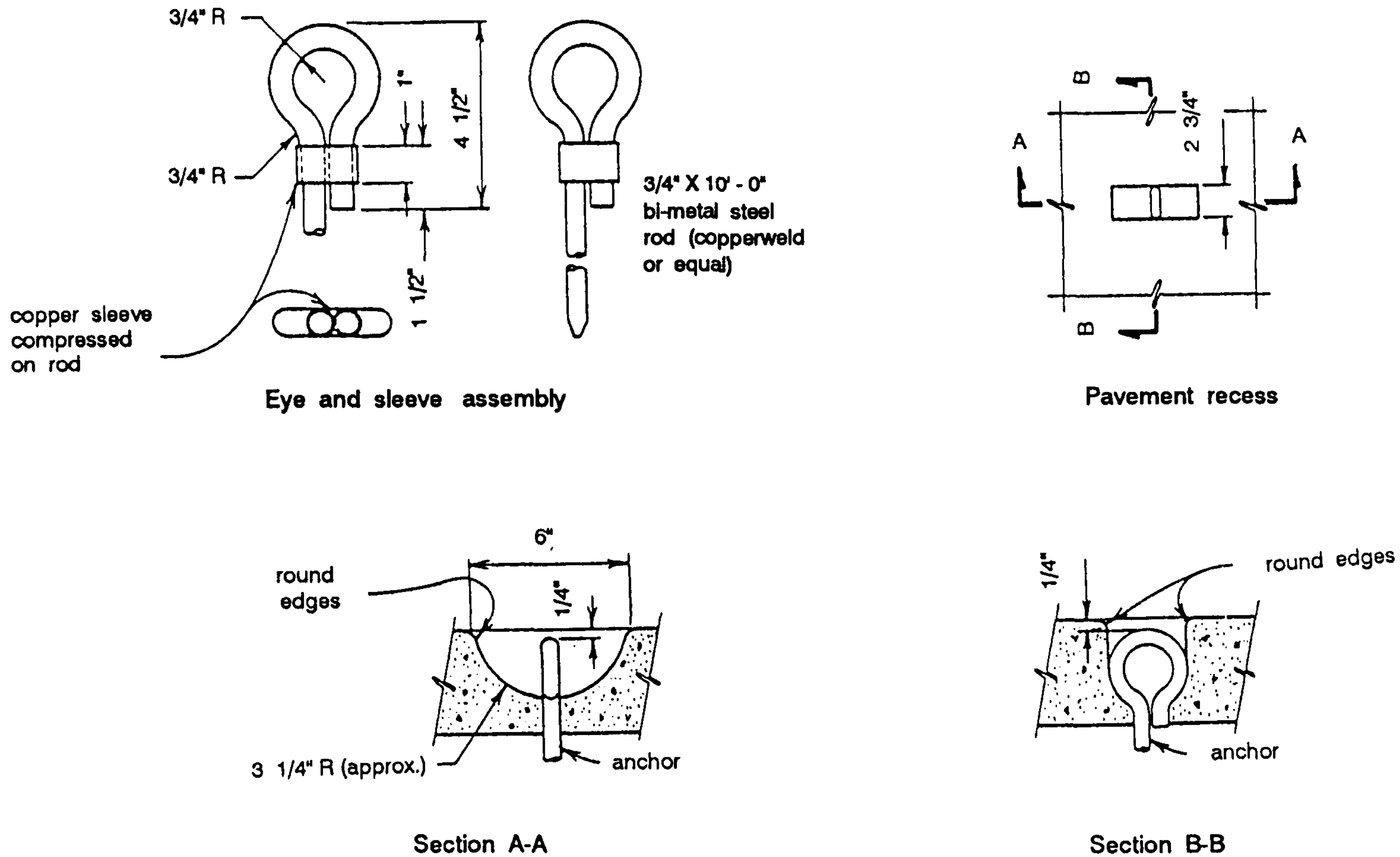


Figure B2. Standard tie-down anchor

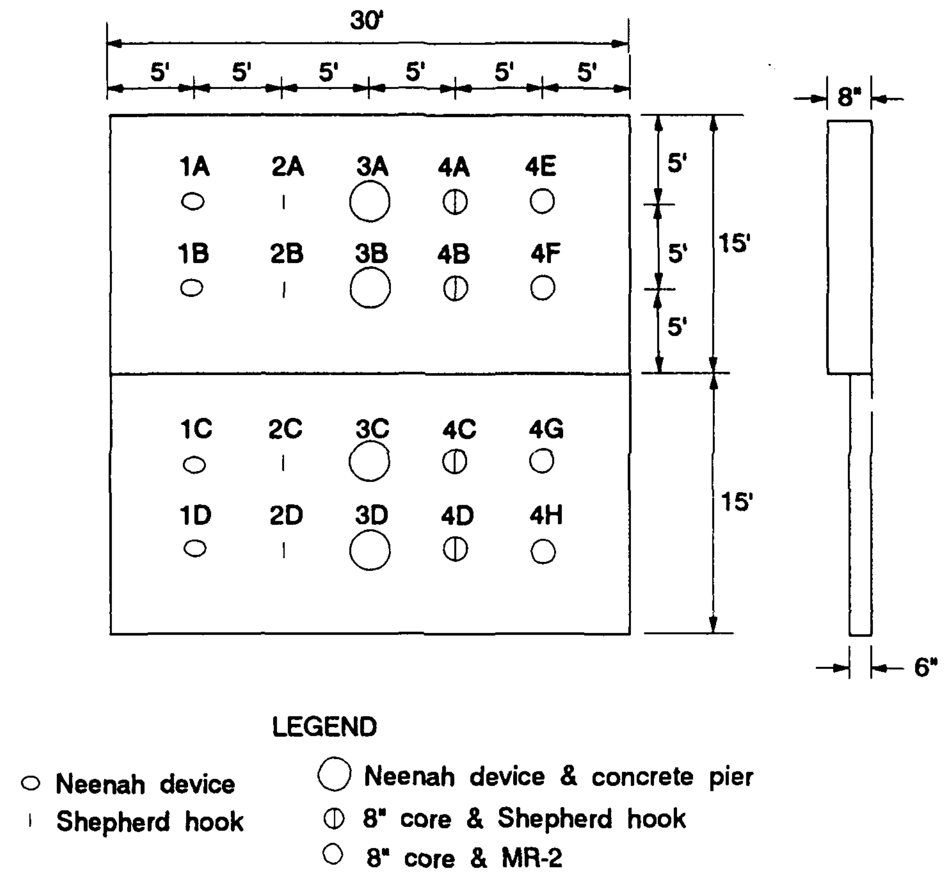
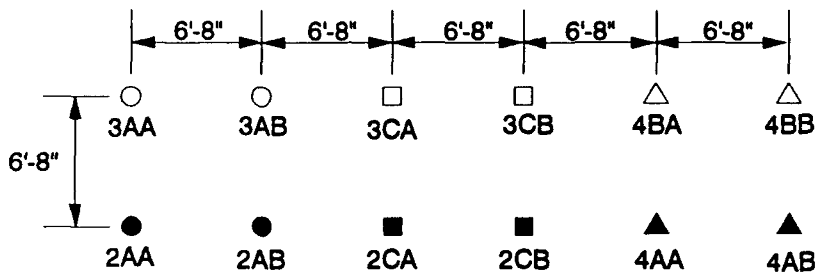


Figure B3. Location of mooring points, concrete slab test site



LEGEND

○ 1.5' diam. by 6' deep with Neenah device

□ 1.5' diam. by 4' deep with Neenah device

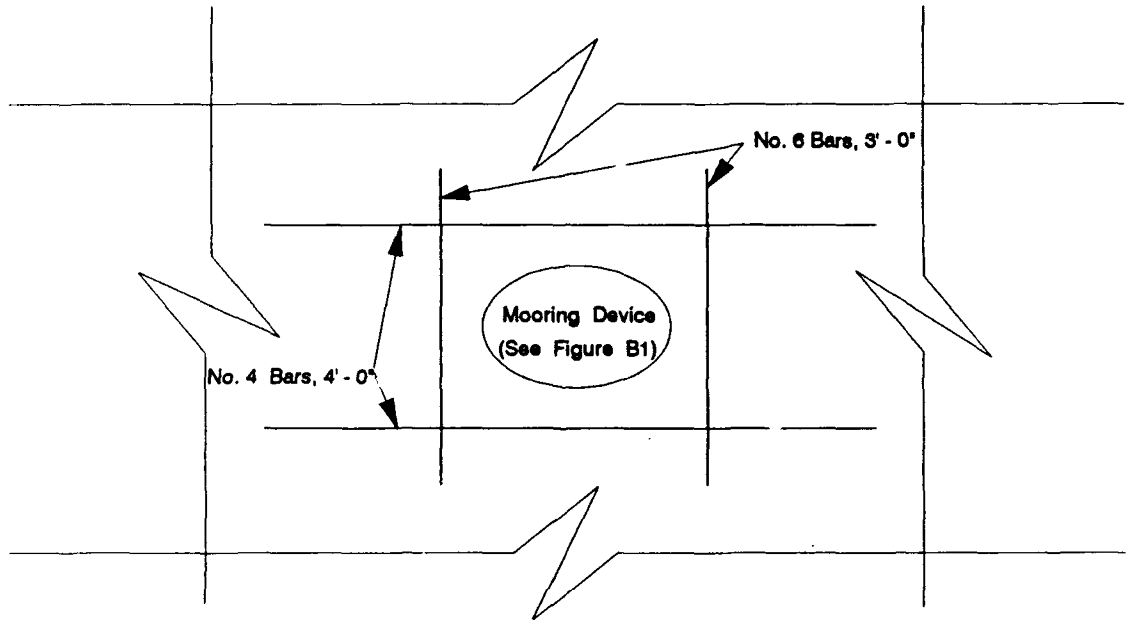
△ 1.5' diam. by 4' deep with Shepherd hook

● 2' diam. by 6' deep with Neenah device

■ 2' diam. by 4' deep with Neenah device

▲ 2' diam. by 4' deep with Shepherd hook

Figure B4. Concrete pier mooring points, soil test site

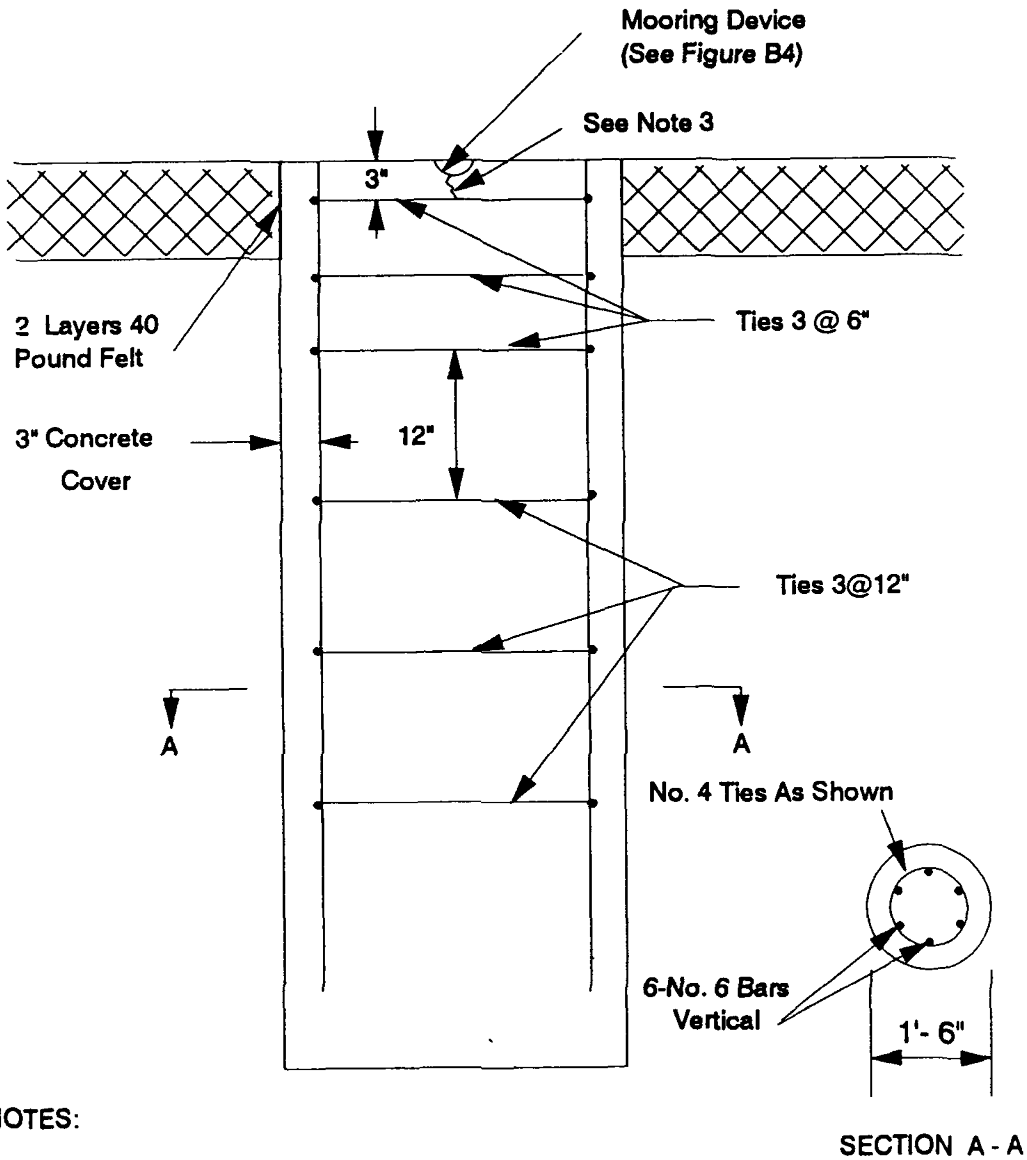


PLAN VIEW

NOTE:

These No. 6 reinforcing bars should be placed 3 in. from the mooring device and 3 in. below the pavement surface.

Figure B5. Mooring device reinforcement, new rigid pavement



NOTES:

1. Pier length 6 ft.
2. Spiral reinforcement equivalent to the No. 4 ties may be used.
3. Connect mooring device to reinforcing steel with No. 4 copper conductor exothermically welded in two places.

Figure B6. Mooring point for existing rigid pavement, pavement thickness 6 or 8 in.

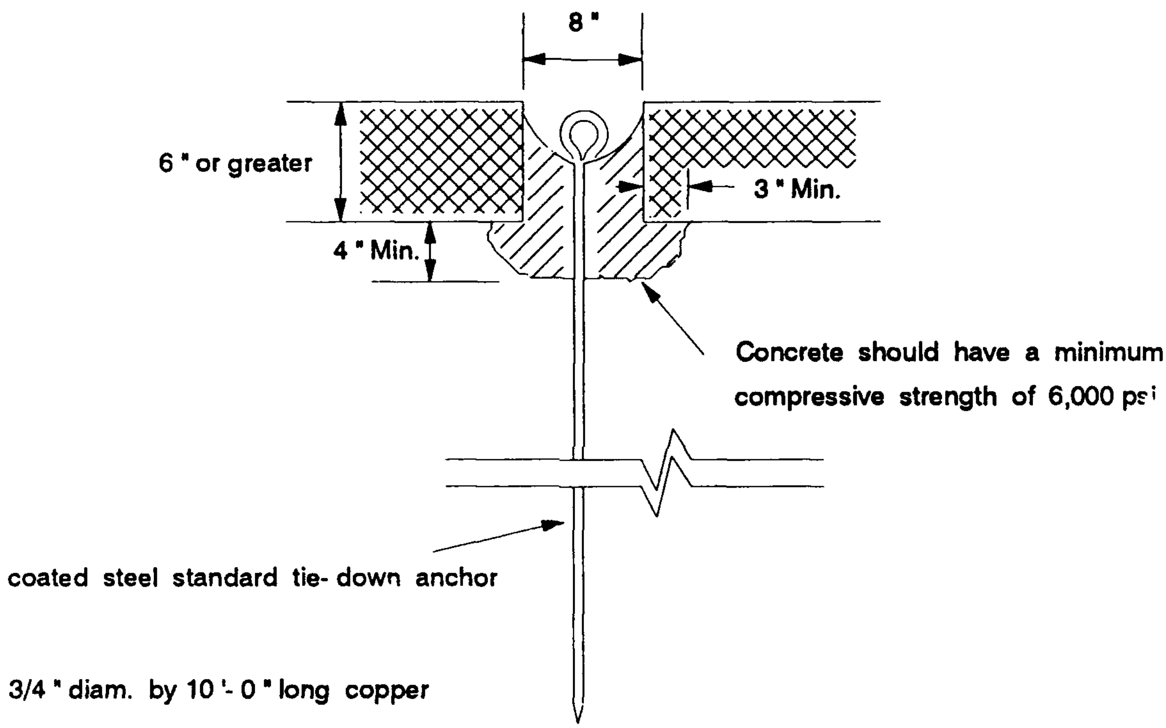
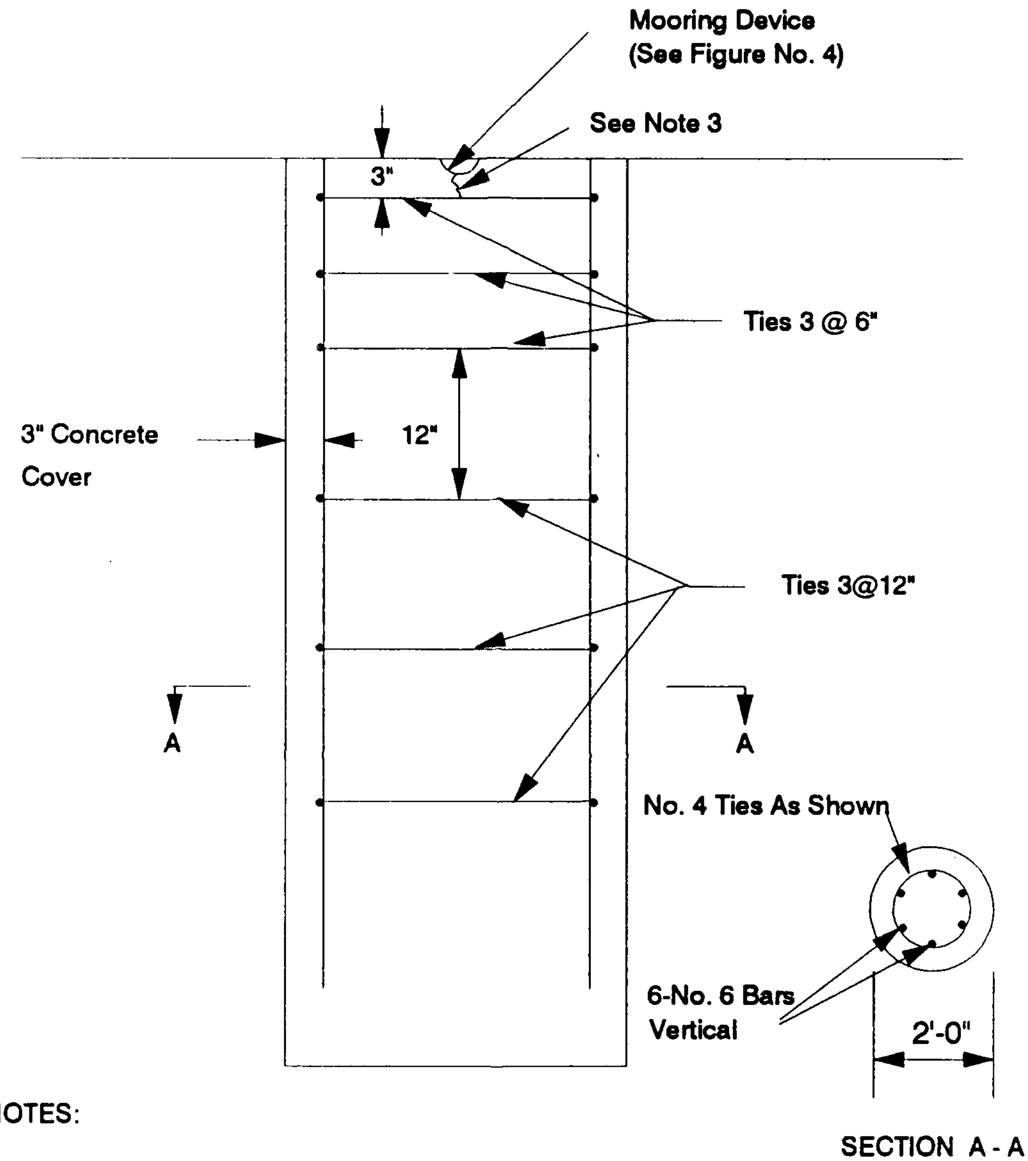


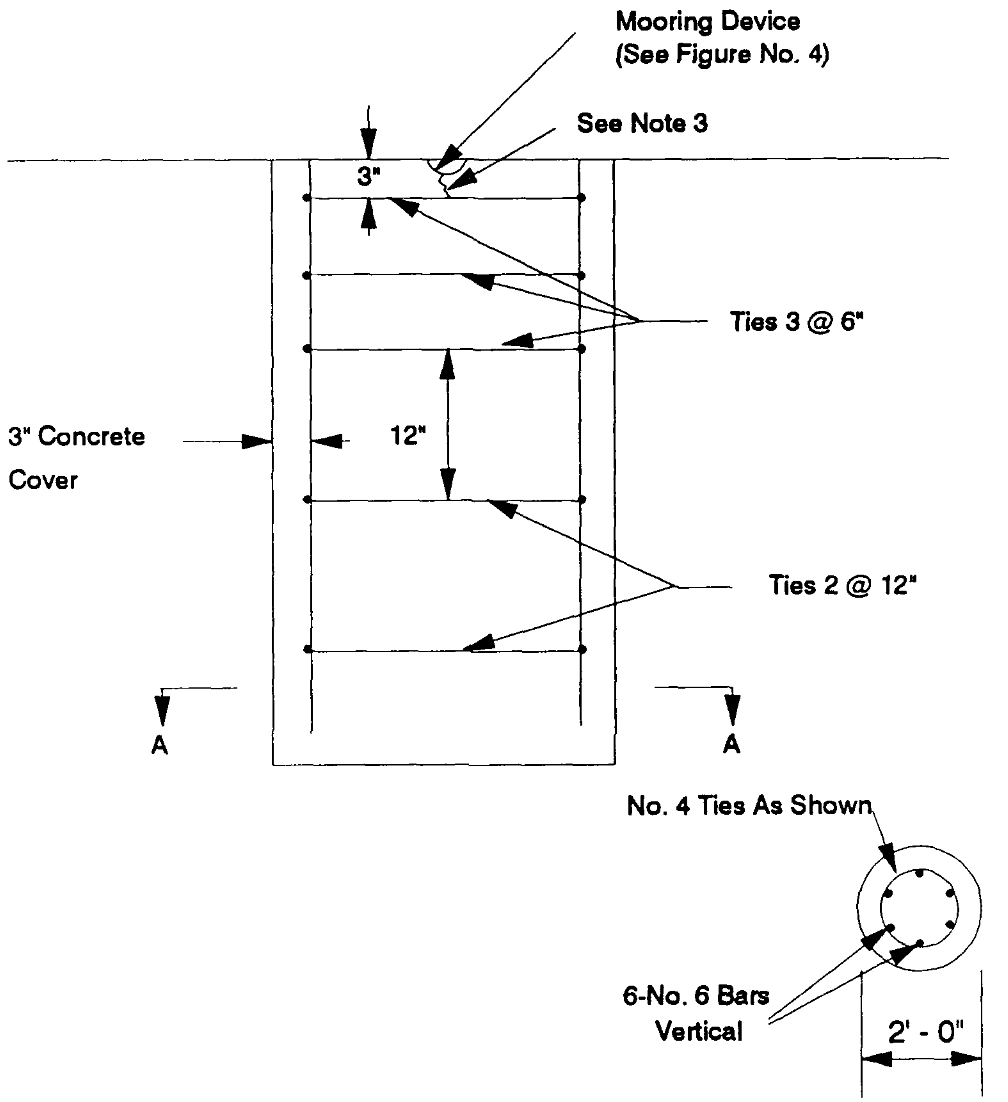
Figure B7. Mooring point for existing rigid pavement, pavement thickness 6 or 8 in.



NOTES:

1. Pier length 6 ft.
2. Spiral reinforcement equivalent to the No.4 ties may be used.
3. Connect mooring device to reinforcing steel with No. 4 copper conductor exothermically welded in two places.

Figure B8. Mooring point for soil, 6 ft long by 2 ft diam.

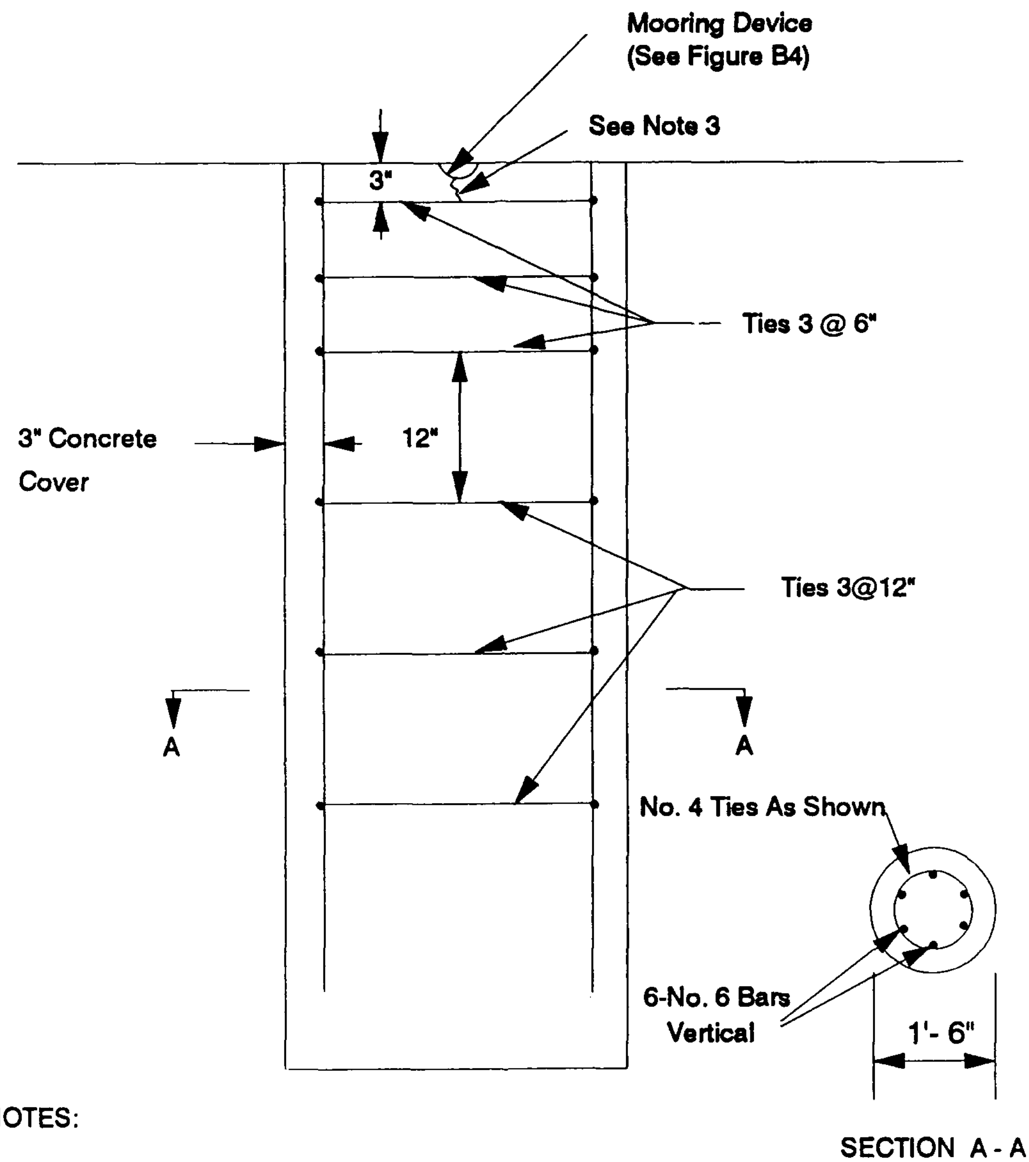


NOTES:

SECTION A - A

1. Pier length 4 ft.
2. Spiral reinforcement equivalent to the No. 4 ties may be used.
3. Connect mooring device to reinforcing steel with No. 4 copper conductor exothermically welded in two places.

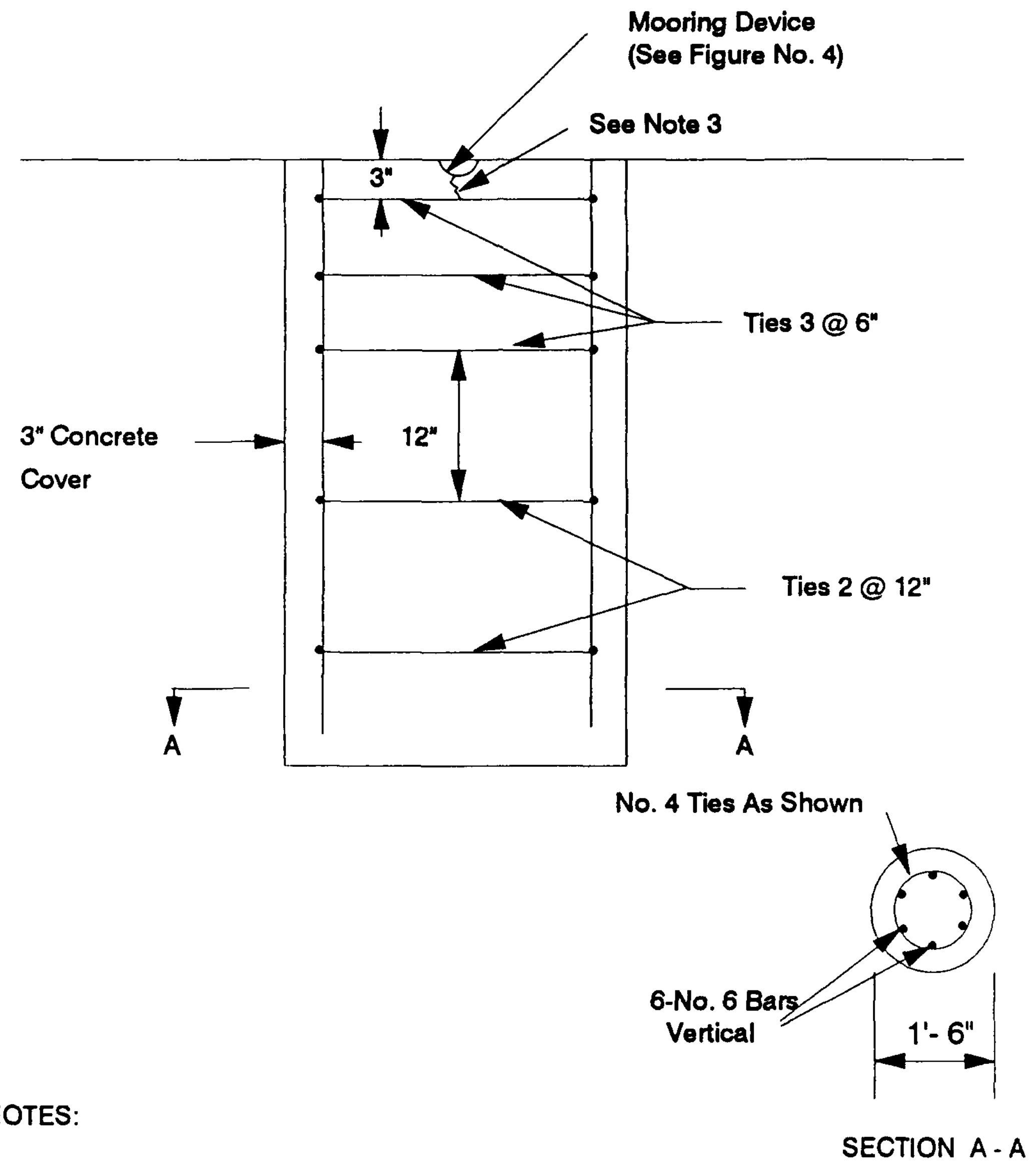
Figure B9. Mooring point for soil, 4 ft long by 2 ft diam.



NOTES:

1. Pier length 6 ft.
2. Spiral reinforcement equivalent to the No. 4 ties may be used.
3. Connect mooring device to reinforcing steel with No. 4 copper conductor exothermically welded in two places.

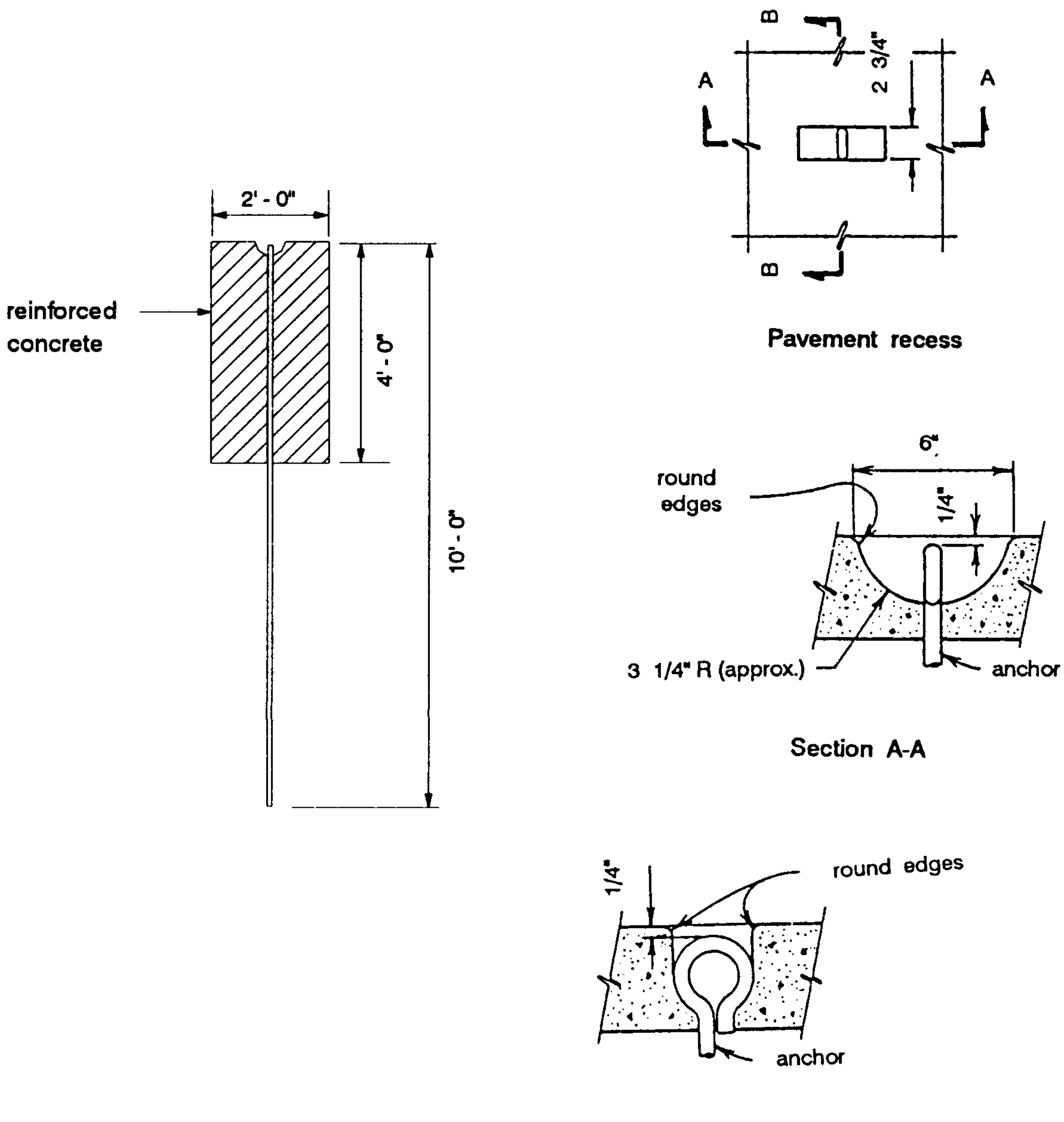
Figure B10. Mooring point for soil, 6 ft long by 1.5 ft diam.



NOTES:

1. Pier length 4 ft.
2. Spiral reinforcement equivalent to the No. 4 ties may be used.
3. Connect mooring device to reinforcing steel with No. 4 copper conductor exothermically welded in two places.

Figure B11. Mooring point for soil, 4 ft long by 1.5 ft diam.

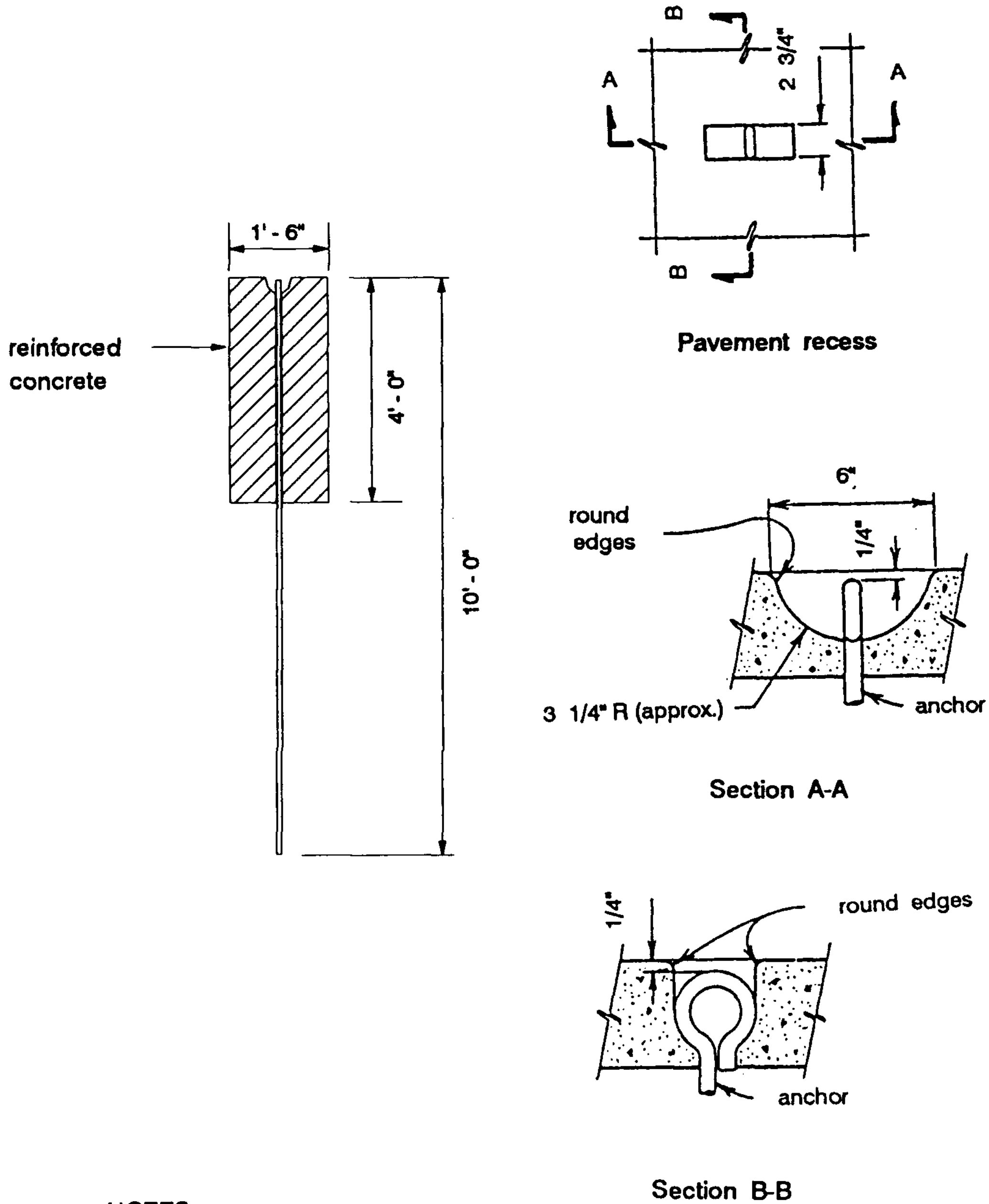


Section B-B

NOTES:

1. Auger hole as shown.
2. Drive anchor into the ground.
3. Fill hole with reinforced concrete.
4. Form recess around anchor eye as shown.

Figure B12. Mooring point for soil, 2 ft diam. with shepherd hook



NOTES:

1. Auger hole as shown.
2. Drive anchor into the ground.
3. Fill hole with reinforced concrete.
4. Form recess around anchor eye as shown.

Figure B13. Mooring point for soil, 1.5 ft diam. with shepherd hook

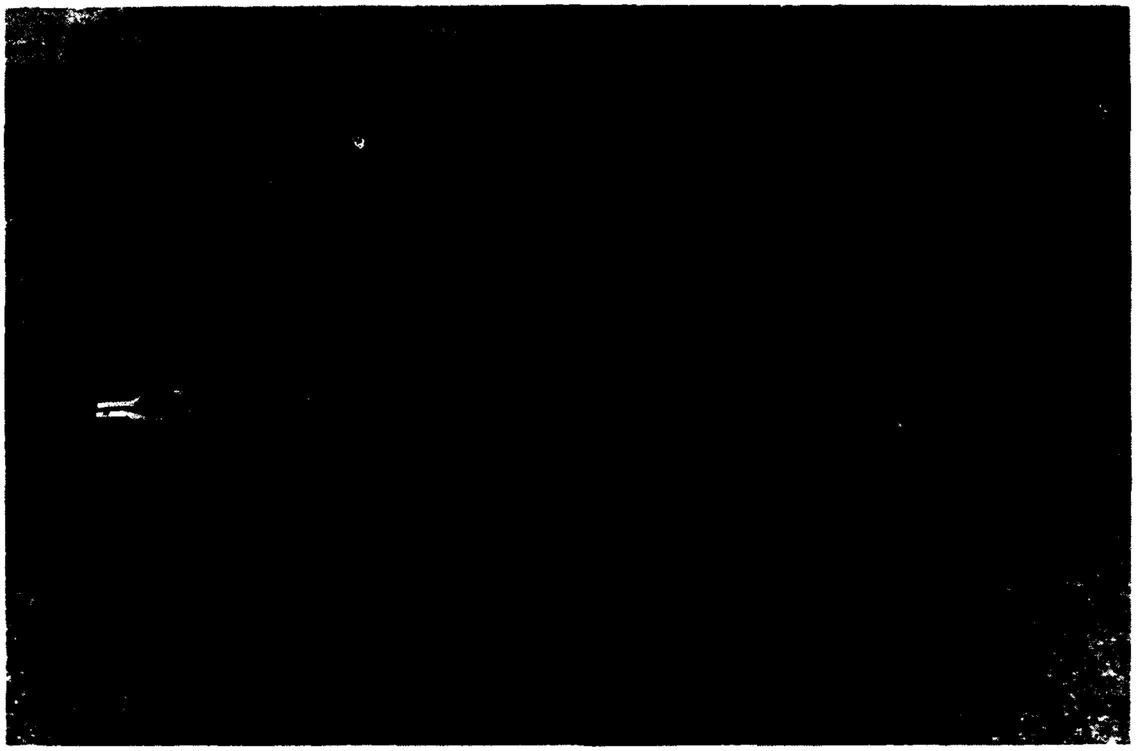


Photo B1. Manta Ray anchoring device

Photo B2. Installing Manta Ray

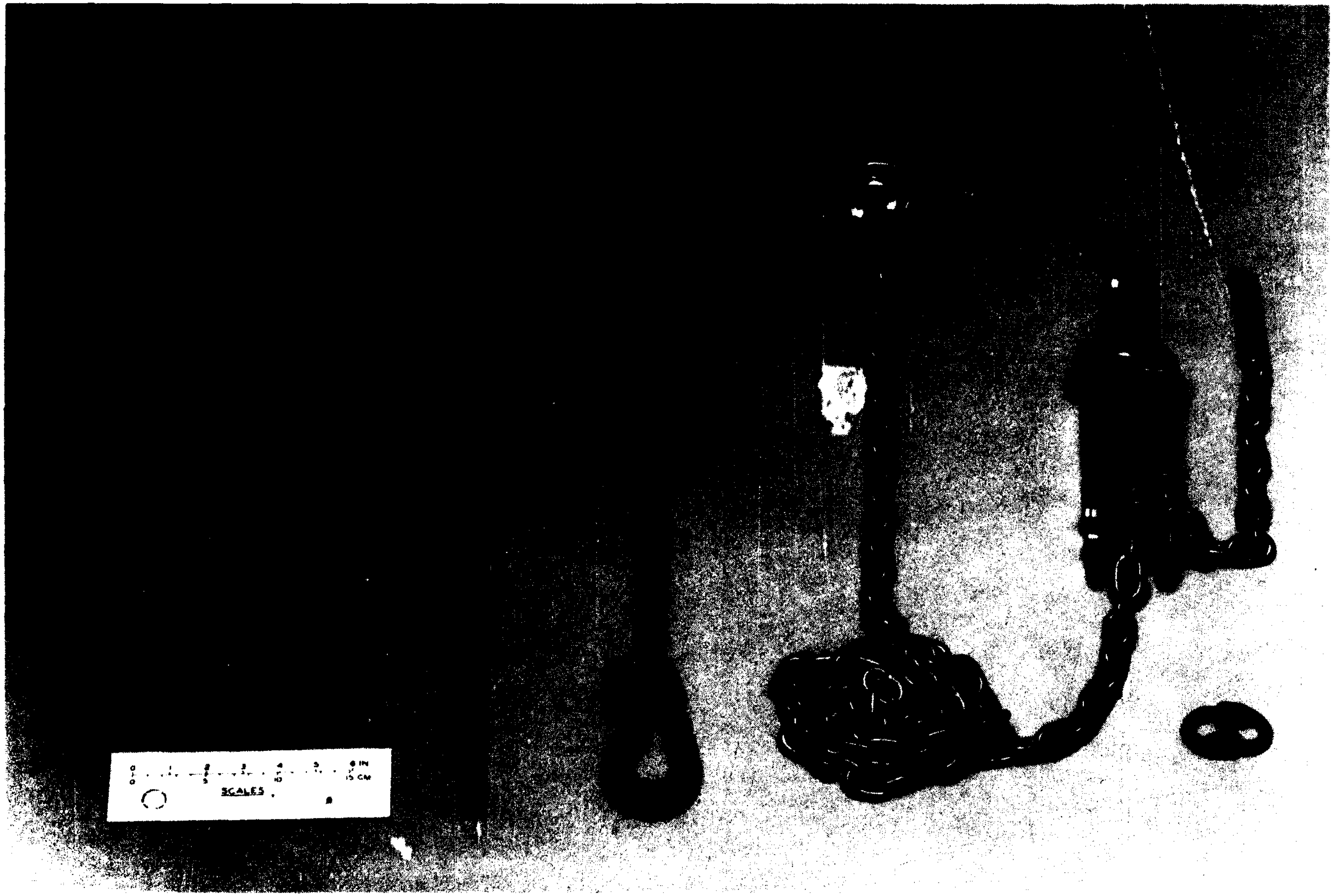


Photo B3. From left to right: 5/8-in.-diam rod, 3/4-in.-diam rod, 1-in.-diam rod, 5/8-in.-diam standard tie-down anchor, 3/4-in.-diam standard tie-down anchor, chain, link chain adjuster (ratchet), and coupling link

Photo 4B. Neenah device prior to placement of concrete

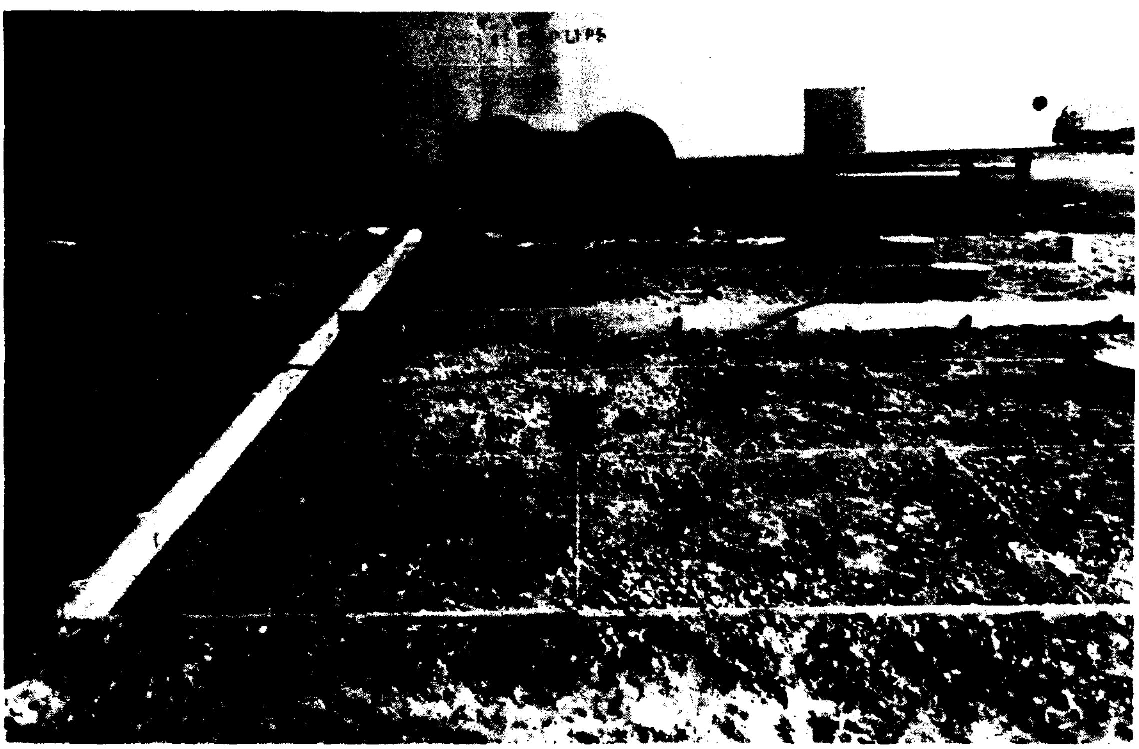


Photo 5B. Standard tie-down anchor (right) prior to placement of concrete

Photo B6. Metal form to provide hole after placement for anchor 3

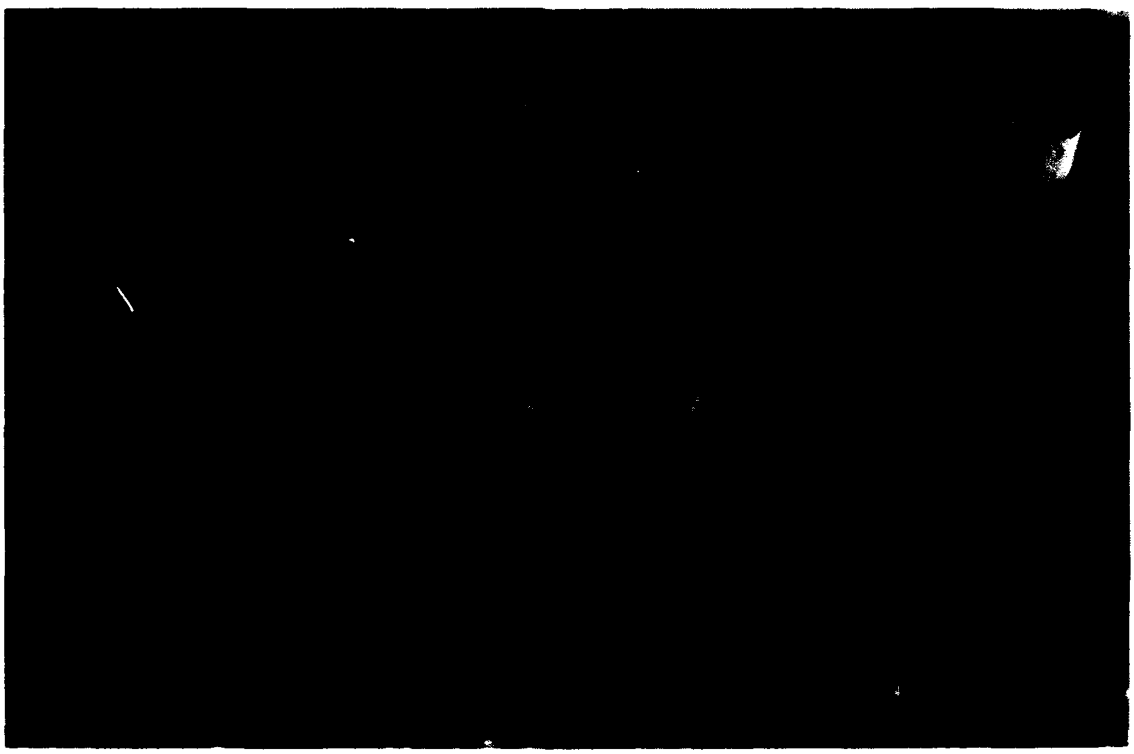


Photo B7. Metal form filled with limestone (anchor 3)

Photo B8. Typical cage of reinforcing steel

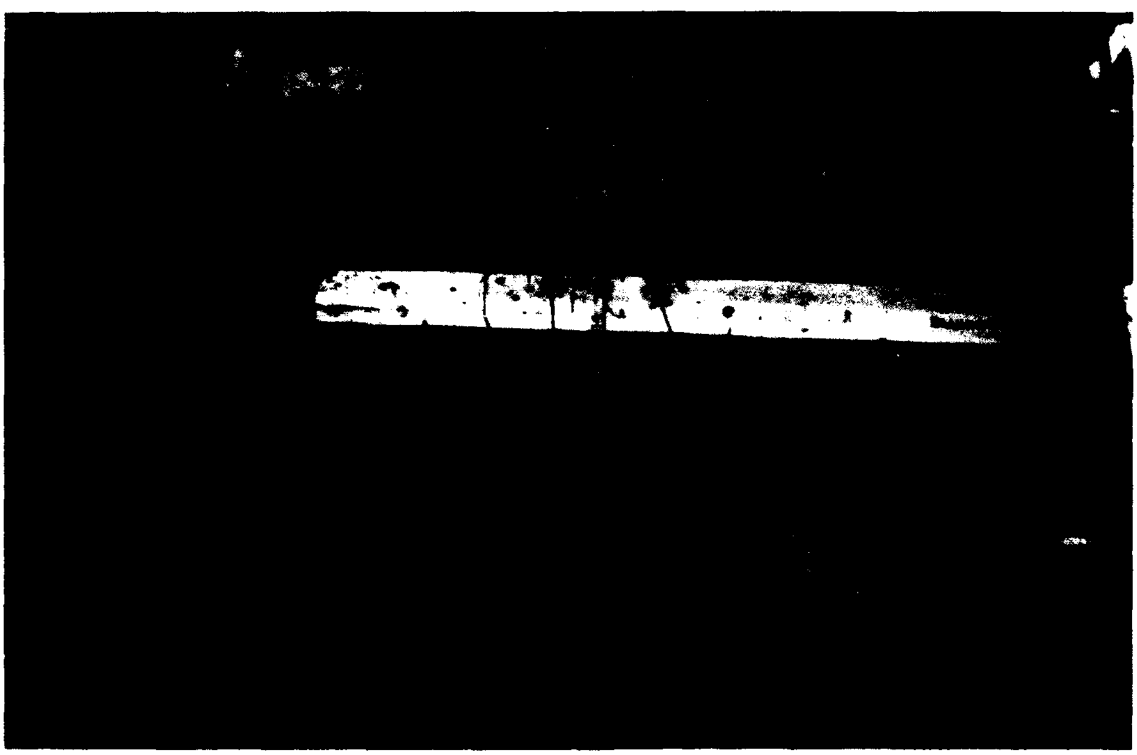


Photo B9. Anchor 3B ready for placement of concrete in anchor hole

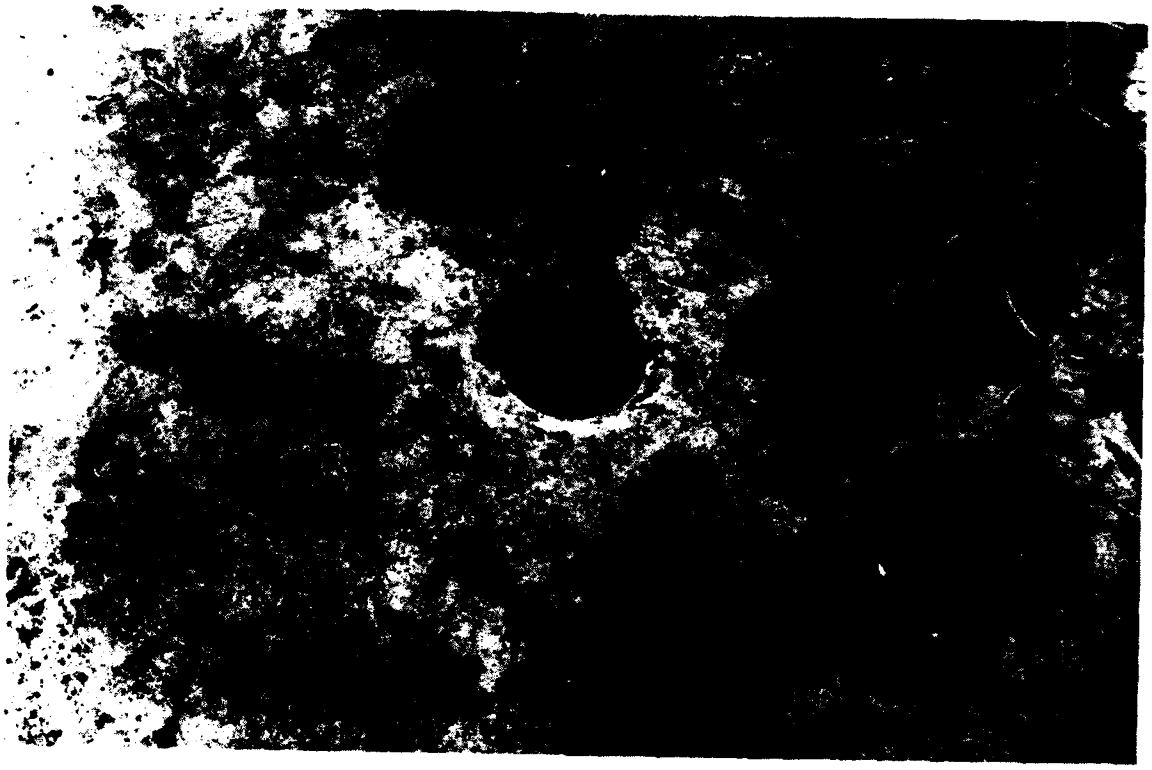


Photo B10. Anchor 4A ready for placement of concrete

Photo B11. Concrete test section after placement of concrete

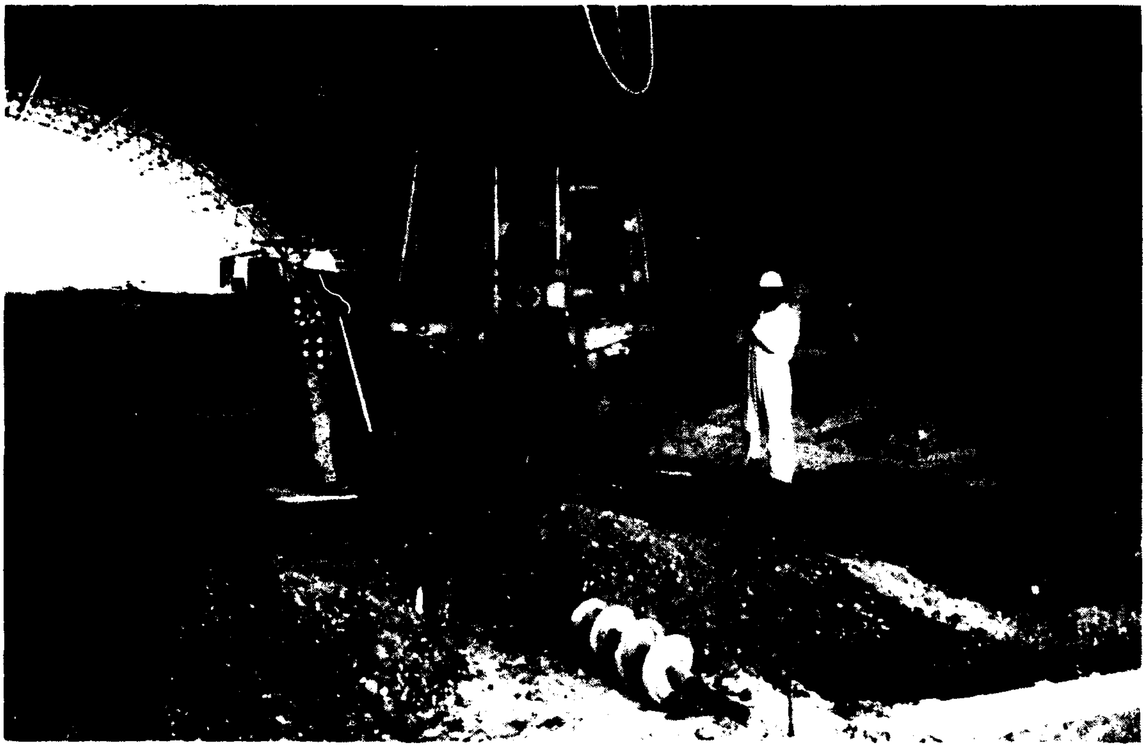


Photo B12. Test rig used to auger anchor holes

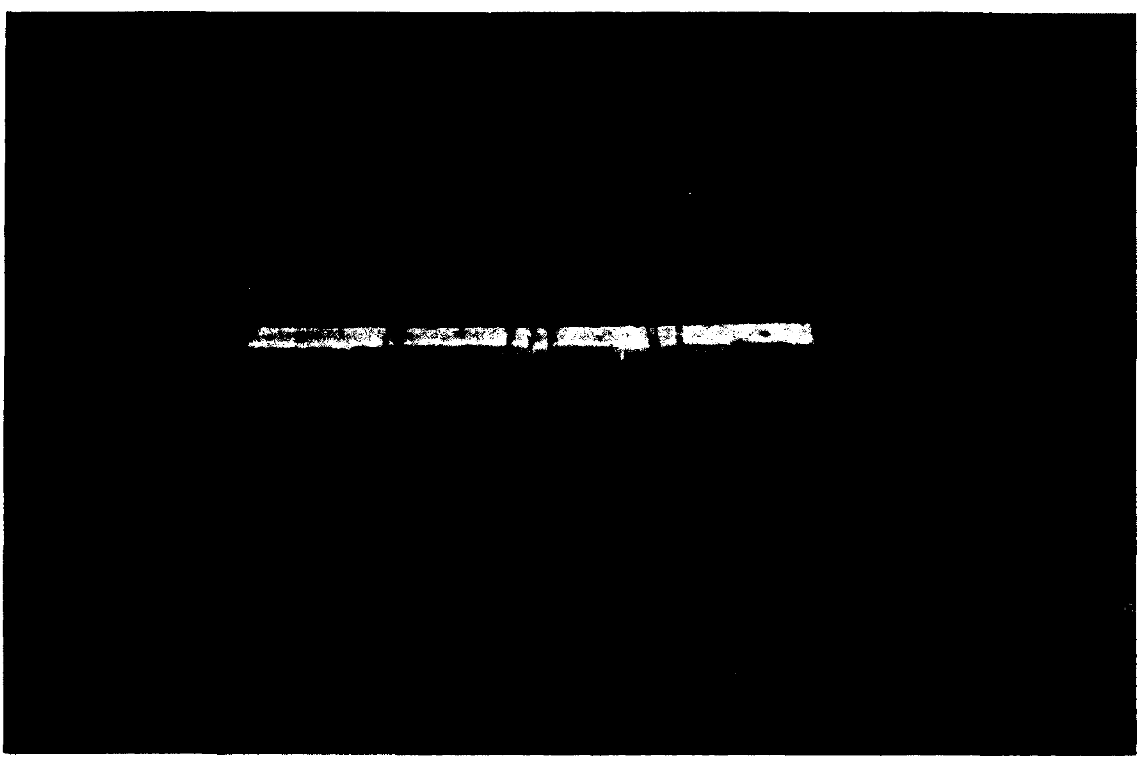


Photo B13. Anchor 2A-A ready for placement of concrete

Photo B14. Anchor 3A-A ready for placement of concrete

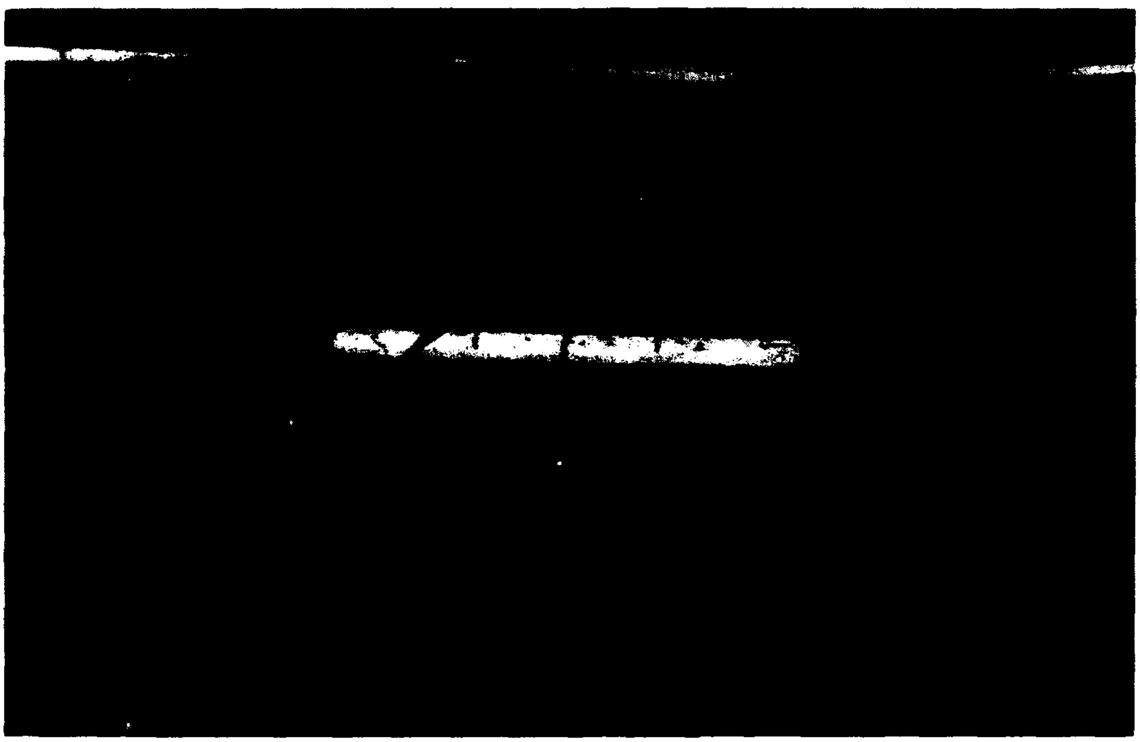


Photo B15. Anchor 4B-A ready for placement of concrete

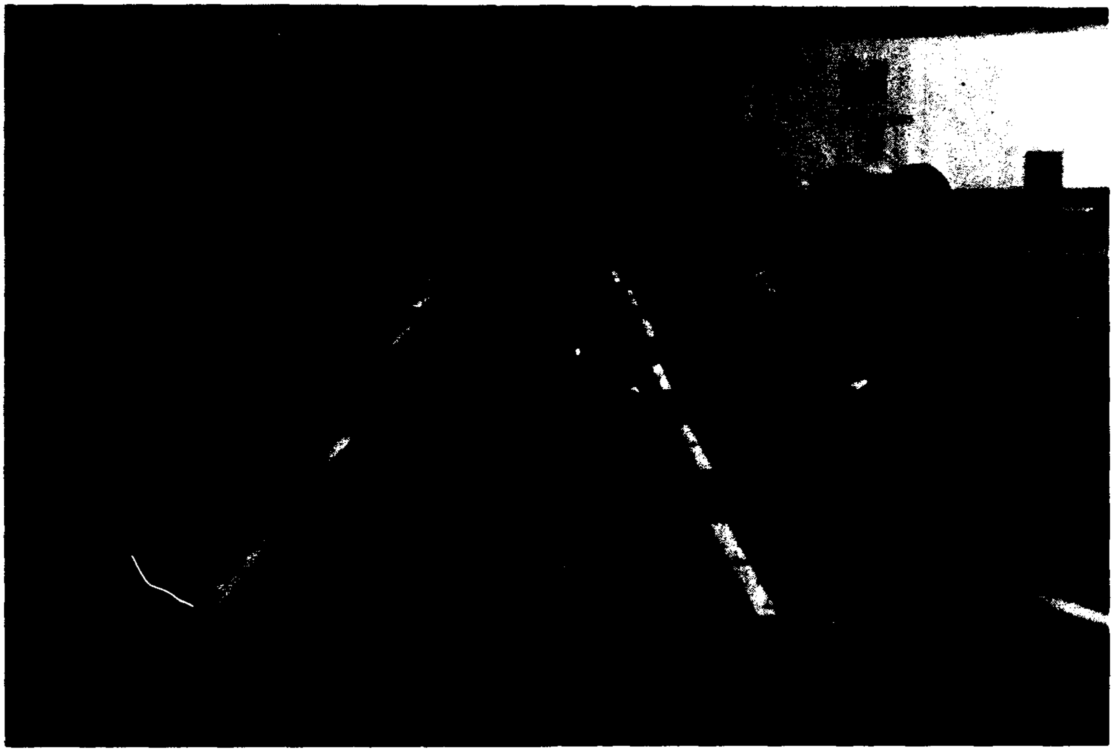


Photo B16. Prepared for placement of concrete

Photo B17. Anchors completed and ready for load pull

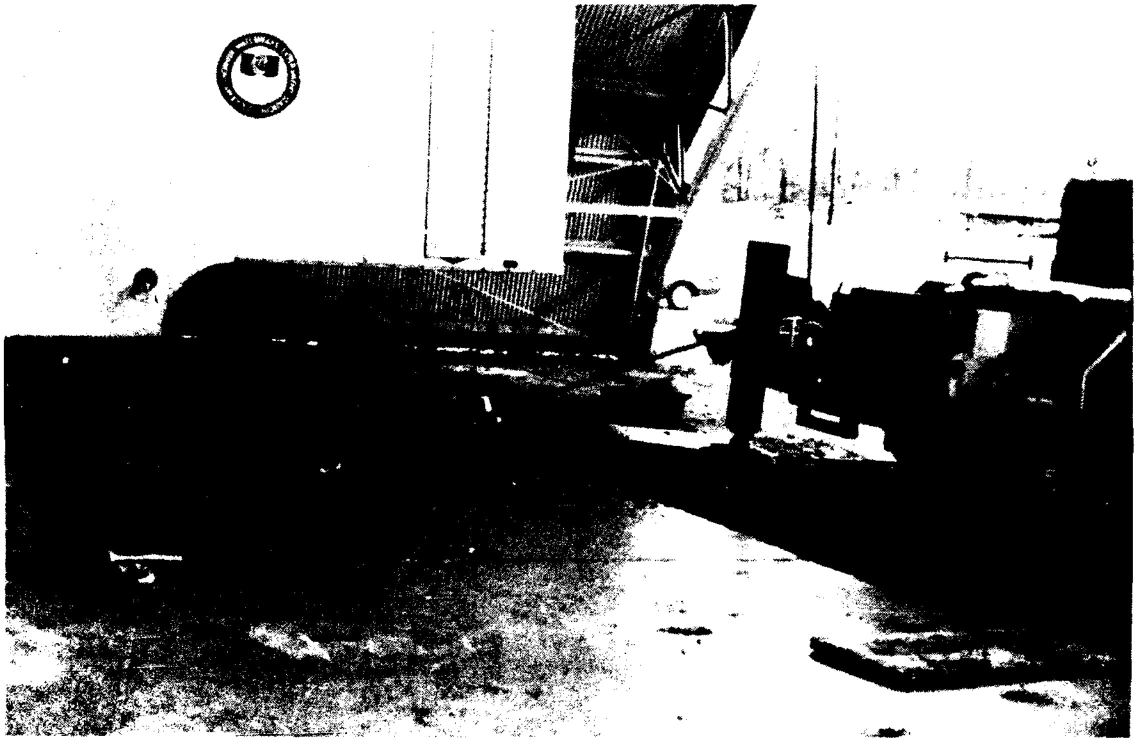


Photo B18. Crane applying force to anchor

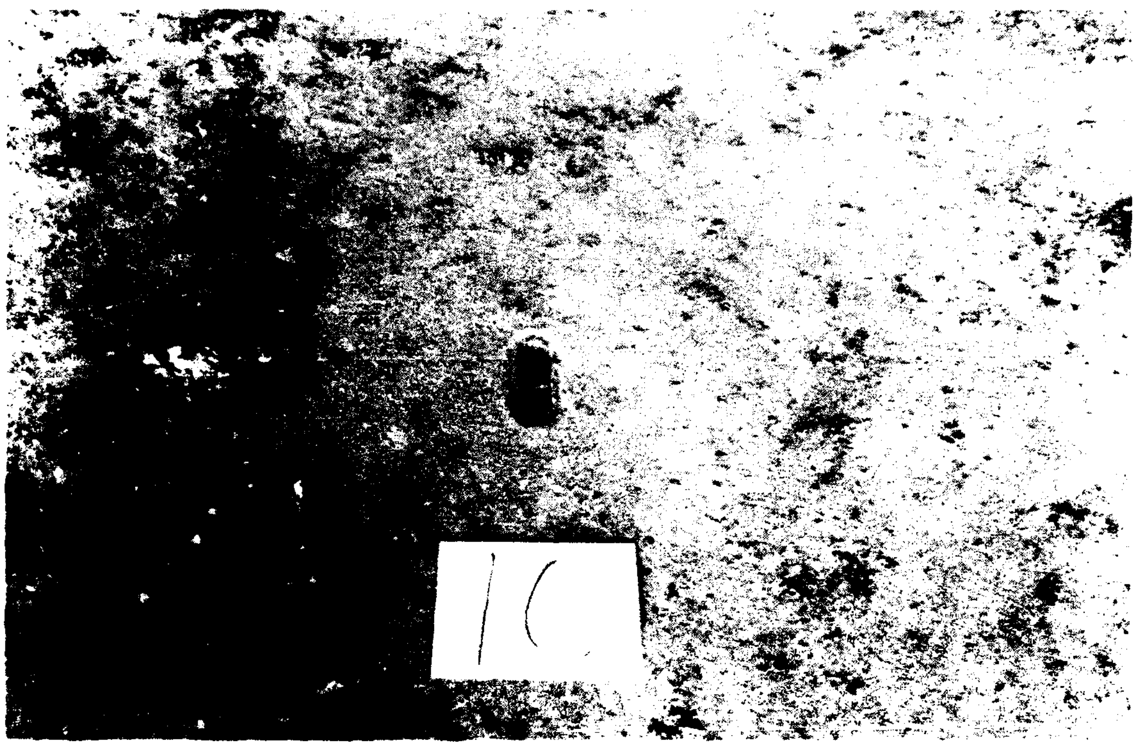


Photo B19. Anchor 1C Neenah device after completion of load pull test

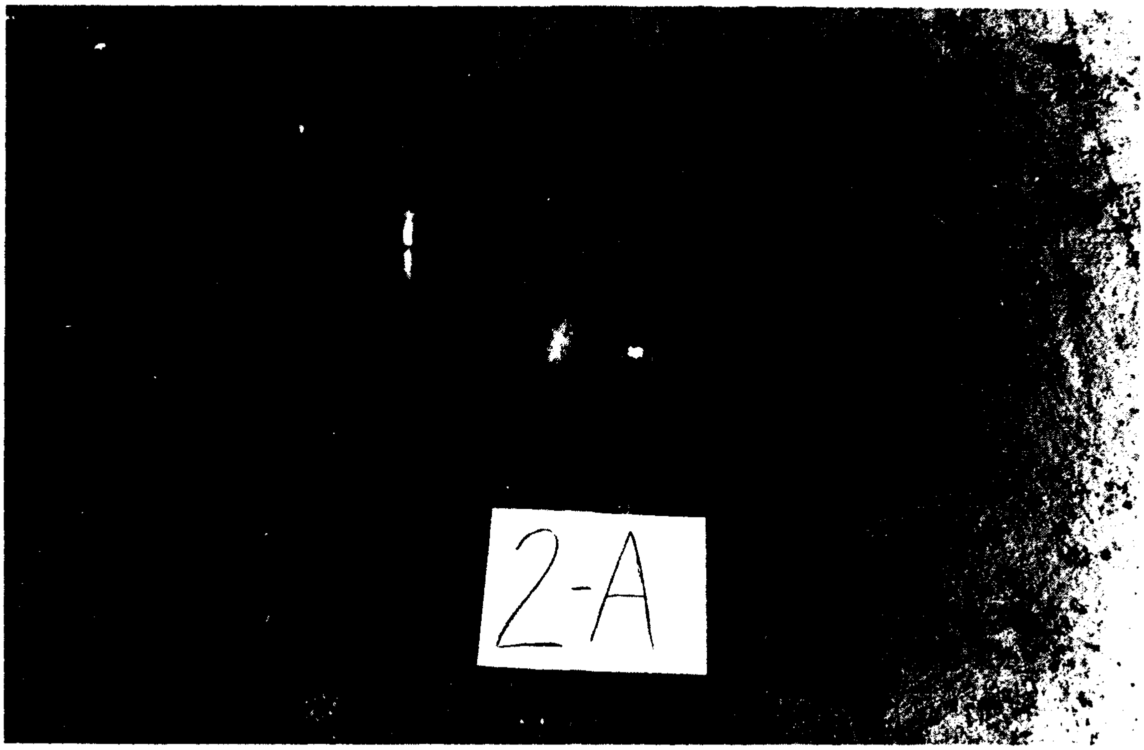


Photo B20. Anchor 2A standard tie-down anchor (shepherd hook) after completion of load pull test

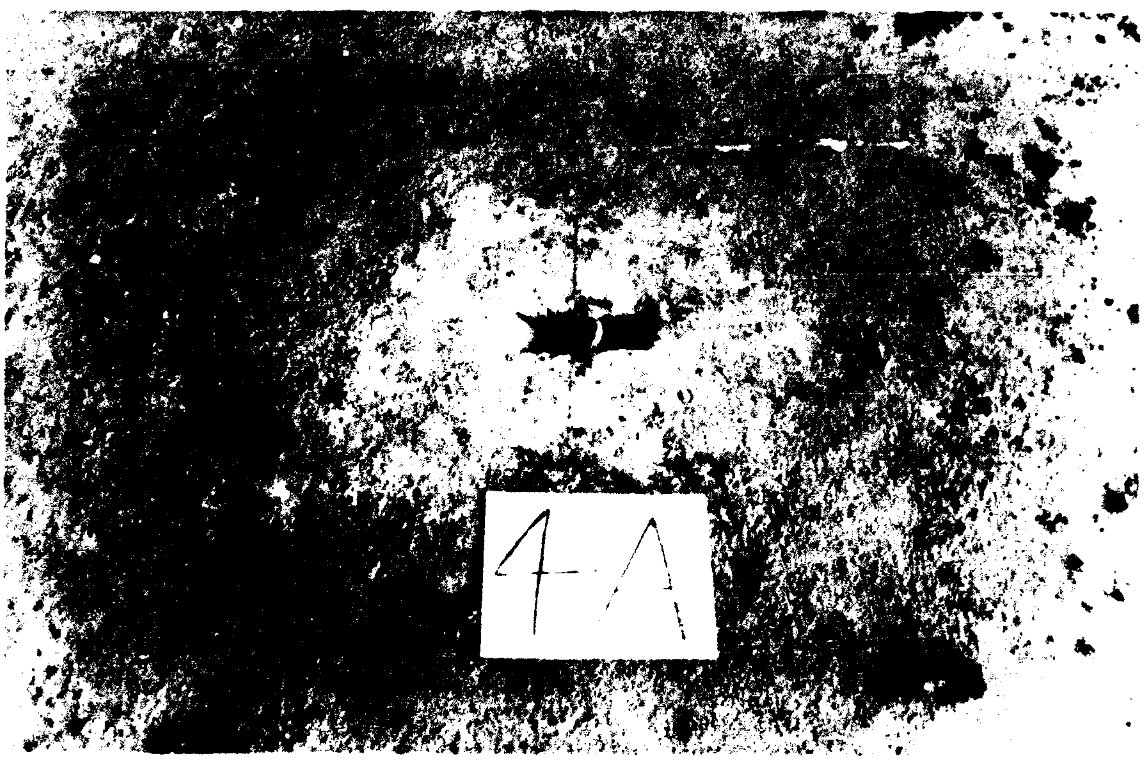


Photo B21. Anchor 4A standard tie-down anchor (shepherd hook) after load pull test

Photo B22. Anchor 2A-A after completion of load pull test

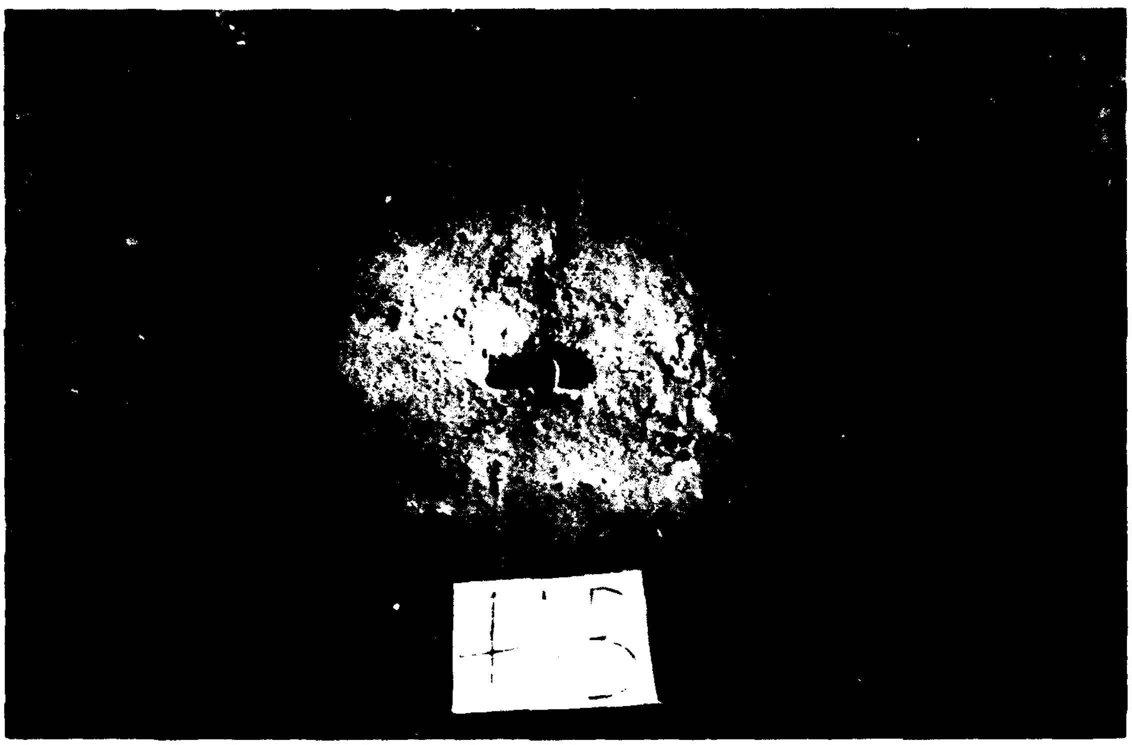


Photo B23. Anchor 4A-B after completion of load pull test

Photo B24. Anchor 4B-B after completion of load pull test